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CONTENTS.

NOTICE TO CONTRIBUTORS.

Contributions intended for publication in any given issue of the MONTHLY WEATHER REVIEW (e. g., January) should be in the hands of the Editor before the end of the next following month (e. g., February), if no illustrations are required. When the paper is illustrated, the manuscript and the copy for the illustrations must be submitted much earlier, in order to permit copy being prepared for the engraver by the end of the month.

REPRINTS are made up without covers in the original size and pagination of the REVIEW. They will not be furnished unless specifically REQUESTED WHEN THE MANUSCRIPT IS SUBMITTED.

MONTHLY WEATHER REVIEW

Cleveland Abbe, jr., Acting Editor.

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INTRODUCTION.

As explained in this Introduction during 1914, the Monthly Weather Review now takes the place of the Bulletin of the Mount Weather Observatory and of the voluminous publication of the climatological service of the Weather Bureau. The Monthly Weather Review contains contributions from the research staff of the Weather Bureau and also special contributions of a general character in any branch of meteorology and climatology.

Supplements to the Monthly Weather Review will be published from time to time.

The climatological service of the Weather Bureau is maintained in all its essential features, but its publications, so far as they relate to purely local conditions, are incorporated in the monthly reports "Climatological Data" for the respective States, Territories, and colonies.

Beginning August, 1915, the material for the Monthly Weather Review has been prepared and classified in accordance with the following sections:

Section 1.—*Aerology.*—Data and discussions relative to the free atmosphere.

Section 2.—*General meteorology.*—Special contributions by any competent student bearing on any branch of meteorology and climatology, theoretical or otherwise.

Section 3.—*Forecasts and general conditions of the atmosphere.*

Section 4.—*Rivers and floods.*

Section 5.—*Seismology.*—Results of observations by Weather Bureau observers and others as reported to the Washington office. Occasional original papers by prominent students of seismological phenomena.

Section 6.—*Bibliography.*—Recent additions to the Weather Bureau library; recent papers bearing on meteorology.

Section 7.—*Weather of the month.*—Summary of local weather conditions; climatological data from regular Weather Bureau stations; tables of accumulated and excessive precipitation; data furnished by the Canadian Meteorological Service; monthly charts Nos. 1, 2, 3, 4, 5, 6, 7, 8, the same as hitherto; Meteorological Summary and chart No. 9 of the North Atlantic Ocean for this month in 1915. Owing to the fact that ocean meteorological data are frequently not available for a considerable time after the close of the month to which they relate, the chart and text matter in connection therewith appear one year late.

In general, appropriate officials prepare the seven sections above enumerated; but all students of atmospherics are cordially invited to contribute such additional articles as seem to be of value.

The voluminous tables of data and text relative to local climatological conditions, that during recent years were prepared by the 12 respective "district editors," are omitted from the Monthly Weather Review but collected and published by States at selected section centers.

The data needed in Section 7 can only be collected and prepared several weeks after the close of the month designated on the title-page; hence the Review as a whole can only issue from the press within about eight weeks from the end of that month.

It is hoped that the meteorological data hitherto contributed by numerous independent services will continue as in the past. Our thanks are especially due to the directors and superintendents of the following:

The Meteorological Service of the Dominion of Canada.
The Meteorological Service of Cuba.
The Meteorological Observatory of Belén College, Habana.
The Government Meteorological Office of Jamaica.
The Meteorological Service of the Azores.
The Meteorological Office, London.
The Danish Meteorological Institute.
The Physical Central Observatory, Petrograd.
The Philippine Weather Bureau.

The Weather Bureau desires that the Monthly Weather Review shall be a medium of publication for contributions within its field, but such publication is not to be construed as official approval of the views expressed.

SECTION I.—AEROLOGY.

SOLAR AND SKY RADIATION MEASUREMENTS DURING APRIL, 1916.

By Herbert H. Kimball, Professor of Meteorology.

[Dated: Washington, D. C., May 25, 1916.]

For a description of instrumental exposures, and an account of the methods of obtaining and reducing the measurements, the reader is referred to the Review for January, 1916, **44**:2.

The monthly means and departures from normal values given in Table 1, show that direct solar radiation intensities were generally below normal at Washington, and above normal at Madison and Santa Fe. A noon maximum intensity of 1.64 gram-calories per minute per square centimeter, measured at Santa Fe on the 8th, exceeds by 4 per cent any previous April noon measurement at that station, and nearly equals the station maximum for the year.

At Washington on the morning of the 10th, at Madison on the morning of the 6th and the afternoon of the 14th, at Lincoln on the morning of the 1st, and at Santa Fe on the mornings of the 20th and 21st, the measurements indicate steady sky conditions throughout most of the respective half-day periods. Extrapolating to zero air mass and reducing to mean solar distance of the earth, the measurements give radiation intensities of 1.78, 1.79, 1.78, 1.80, 1.81, and 1.81 gram-calories per minute per square centimeter, respectively. Allowing for the probable differences in the water-vapor content of the atmosphere at the several stations, due not only to their differences in elevation above sea level, but also to the differences in the surface vapor pressure, as shown in Table 2, the above determinations are in close agreement. Applying the Smithsonian "Abridged procedure for determining approximately the value of the solar constant" [1] to the Santa Fe measurements of April 20 and 21, we obtain 1.90 gram-calories, or a little less than Abbot's mean value of the solar constant.

Table 1.—*Solar radiation intensities during April, 1916.*

[Gram-calories per minute per square centimeter of normal surface.]

Santa Fe, N. Mex.

Date.	Sun's zenith distance.									
	0.0°	48.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°
	Air mass.									
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
A. M.	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*
Apr. 1			1.39	1.33	1.26		1.17	1.10		
6	1.59	1.51	1.41							
7	1.60	1.55	1.47	1.34	1.31	1.27	1.22	1.17	1.12	
8	1.67	1.45	1.38	1.29	1.25	1.18	1.08	0.97	0.88	
13	1.62	1.50	1.36	1.26	1.18	1.14				
18		1.42	1.32	1.23		1.12	1.05			
20	1.61	1.56	1.45	1.38	1.32	1.27	1.20	1.05		
21	1.61	1.52	1.44	1.38	1.31	1.25	1.17			
Monthly means	**1.62**	**1.50**	**1.40**	**1.32**	**1.27**	**1.20**	**1.15**	**1.07**	**(1.00)**	
Departure from 4-year normal	**+0.06**	**+0.06**	**+0.02**	**+0.05**	**+0.06**	**+0.02**	**±0.00**	**±0.00**	**±0.00**	

[1] Annals of the Astrophysical Observatory of the Smithsonian Institution, Washington, 1908, 2:115.

Table 1.—*Solar radiation intensities during April, 1916*—Continued.

Washington, D. C.

Date.	Sun's zenith distance.									
	0.0°	47.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°
	Air mass.									
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
A. M.	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*
Apr. 7		1.32	1.26	1.21	1.12	1.06	1.00	0.97		
10	1.44	1.31	1.17	1.05	0.97	0.90	0.82	0.73	0.65	0.62
11	1.33	1.20	1.12	1.00	0.89	0.81	0.74	0.68	0.64	0.60
12	1.28	1.22	1.11	1.04	0.97	0.88	0.79	0.73	0.68	0.63
15							1.01	0.95	0.90	
18		1.32	1.22	1.13	1.04	0.95	0.87	0.80		0.67
19		1.13	1.07	0.91	0.78	0.69	0.61	0.55	0.47	0.40
20	1.02									
24			0.97	0.84	0.75	0.68	0.61	0.55		
26		1.00	0.84	0.74	0.67	0.57	0.50	0.45		
29		0.96	0.76	0.67	0.57	0.47				
30		1.16	1.06	0.94	0.83					
Monthly means	**1.27**	**1.18**	**1.06**	**0.95**	**0.86**	**0.78**	**0.77**	**0.71**	**0.67**	**0.58**
Departure from 8-year normal	**−0.11**	**±0.00**	**−0.01**	**−0.03**	**−0.05**	**−0.06**	**+0.03**	**−0.03**	**−0.03**	**−0.06**
P. M.										
Apr. 5		1.05								
10		1.22	1.14	1.05	0.95	0.86	0.80	0.74	0.68	
15				1.13	0.99					
Monthly means		**(1.14)**	**(1.14)**	**(1.09)**	**(0.97)**	**(0.86)**	**(0.80)**	**(0.74)**	**(0.68)**	
Departure from 8-year normal		**−0.05**	**+0.08**	**+0.10**	**+0.06**	**−0.02**	**+0.06**	**+0.13**	**+0.13**	
Madison, Wis.										
A. M.										
Apr. 1		1.43	1.36	1.27	1.18	1.11				
6	1.58	1.49	1.40			1.18	1.13			
10		1.20								
11	1.53	1.40								
14	1.51	1.40								
17			1.36	1.28	1.20					
27	1.47	1.37	1.28	1.19	1.11					
28		1.32								
Monthly means	**1.52**	**1.36**	**1.35**	**1.25**	**1.16**	**(1.14)**	**(1.13)**			
Departure from 6-year normal	**+0.10**	**+0.04**	**+0.13**	**+0.12**	**+0.06**	**+0.02**	**±0.00**			
P. M.										
Apr. 6		1.49								
9		1.48								
14		1.40	1.29	1.19	1.11	1.05	0.99			
27		1.35	1.22							
Monthly means		**1.43**	**(1.26)**	**(1.19)**	**(1.11)**	**(1.05)**	**(0.99)**			
Departure from 6-year normal		**+0.07**	**−0.01**	**±0.00**	**±0.00**	**−0.04**	**±0.00**			
Lincoln, Nebr.										
A. M.										
Apr. 1		1.48	1.39	1.30	1.22	1.12		1.01		
9					1.14					
10		1.34	1.23							
11				1.04	0.99	0.94				
19			1.10	1.01	0.94	0.87				
21		1.43	1.30							
24				1.20						
28		1.34	1.25							
Monthly means		**1.40**	**1.25**	**1.14**	**1.07**	**0.98**		**(1.01)**		
P. M.										
Apr. 11	1.42	1.30								
12		1.28								
16		1.25	1.08	0.96	0.87	0.79	0.73		0.61	
21				1.15	1.06	0.99	0.93	0.86	0.78	
23			1.21							
24		1.30	1.18	1.07	0.99	0.94	0.88	0.82	0.75	0.70
Monthly means	**(1.42)**	**1.28**	**1.16**	**1.06**	**0.97**	**0.91**	**0.85**	**(0.84)**	**0.71**	**(0.70)**

Skylight polarization measurements made at Washington on six days give a mean of 52 per cent, with a maximum of 58 per cent on the 11th and 12th. A higher maximum would undoubtedly have been obtained had not the ground been covered with snow on the morning of the 10th.

TABLE 2.—*Vapor pressure at pyrheliometric stations on days when solar radiation intensities were measured.*

Washington, D. C.			Madison, Wis.			Lincoln, Nebr.			Santa Fe, N. Mex.		
Date.	8 a. m.	8 p. m.	Date.	8 a. m.	8 p. m.	Date.	8 a. m.	8 p. m.	Date.	8 a. m.	8 p. m.
1916.	*Mm.*	*Mm.*	1916	*Mm.*	*Mm.*	1916	*Mm.*	*Mm.*	1916	*Mm.*	*Mm.*
Apr. 5	6.02	4.95	Apr. 1	4.57	4.95	Apr. 1	3.99	3.81	Apr. 1	2.87	3.63
7	3.15	3.99	6	1.78	2.87	9	2.74	3.99	7	1.88	1.52
10	3.63	3.99	9	2.06	2.06	10	4.57	5.56	8	2.49	2.62
11	4.75	5.56	10	3.81	5.56	11	6.50	7.04	13	3.45	3.81
12	5.36	4.95	11	6.27	3.15	12	11.81	5.16	18	3.63	3.45
15	3.81	3.99	14	4.37	3.81	16	7.04	4.17	20	2.36	1.52
18	3.63	3.81	17	3.81	3.00	19	10.21	9.47	21	2.26	3.30
19	4.17	3.99	27	4.17	4.57	21	5.16	5.56			
20	6.27	8.48	28	5.56	6.50	23	6.27	5.79			
24	5.56	6.27				24	6.02	3.63			
26	6.02	8.48				28	5.36	5.16			
29	7.87	6.76									
30	6.76	6.76									

In Table 3 are included for the first time the daily totals of radiation for Madison, Wis., and Lincoln, Nebr., as measured by a Callendar pyrheliometer. The measurements made at Madison during the five years ending with March 31, 1916, will be found summarized on pages 180 to 181 of this number of the REVIEW. The daily means for Madison from which the daily departures are computed include the measurements for the current month, and are therefore 6-year means.

The Callendar register was installed at the State university farm, Lincoln, Nebr., on June 30, 1915; therefore, daily means for Lincoln are not yet available. The receiver, No. 9861, is exposed on a small platform about 6 feet above the ridgepole of the experiment station building, 65 feet above the ground, and 1,250 feet, or 381 meters, above sea level. There are practically no obstructions between it and the sky in any direction down to the true horizon.

The receiver was first compared with a Marvin pyrheliometer at Mount Weather, Va., in 1913.[2] After its installation at Lincoln it was further compared with the Marvin pyrheliometer at that station. Care is also exercised to keep the instrument oriented so that the edges of the mica plates supporting the resistance grids are either at right angles to or in the same vertical plane as the incident solar rays, so as to reduce to a minimum the effect of internal reflection from the glass cover of the receiver.[3] Under these conditions the value of a tenth of an inch on the record sheet, expressed in heat units, has been found to be 0.0270 gram-calory per minute per square centimeter, regardless of the zenith distance of the sun. This is practically the same value as was found at Mount Weather with the sun not more than 45° from the zenith. A correction has been applied to this value for blue-sky effect on account of the selective reflection of the platinum wires constituting the bright resistance grid[4]; so that for different degrees of cloudiness the value in heat units of the 0.1 inch ruled spaces on the record sheet is as shown below (Table 4.)

As shown by Table 3, the total radiation averaged below normal during the first and third decades of April at Washington, and during the second and third decades at Madison. At Lincoln it averaged below the Madison normals during the second and third decades, although generally, during the time the register has been in operation there, the decade means have been higher than the Madison normals.

At Washington the deficiency in radiation for the month was 9.7 per cent of the normal radiation for April, and since the first of the year the deficiency has been 9.6 per cent. Madison shows an excess for the month of about 1.1 per cent and a deficiency since the first of the year of about 1.4 per cent, or departures from the normal that are quite insignificant.

TABLE 3.—*Daily totals and departures of solar and sky radiation during April, 1916.*

[Gram-calories per square centimeter of horizontal surface.]

Day of month.	Daily totals.			Departures from normal.		Excess or deficiency since first of month.	
	Washington.	Madison.	Lincoln.	Washington.	Madison.	Washington.	Madison.
1916.	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*
Apr. 1	502	575	596	120	191	120	191
2	292	567	408	−92	180	28	371
3	108	422	170	−278	33	−250	404
4	120	426	501	−268	34	−518	438
5	417	519	520	27	125	−491	563
6	304	639	309	−89	242	−580	805
7	465	261	238	70	−138	−510	667
8	78	589	375	−320	187	−830	854
9	260	631	558	−141	227	−971	1,081
10	571	552	514	168	145	−803	1,226
11	554	498	594	148	88	−655	1,314
12	575	220	559	166	−192	−489	1,122
13	342	338	179	−70	−77	−559	1,045
14	313	634	520	−102	217	−661	1,262
15	603	430	111	185	10	−476	1,272
16	557	215	504	135	−207	−341	1,065
17	323	682	307	−104	257	−445	1,322
18	578	310	363	147	−117	−298	1,205
19	541	310	384	105	−120	−193	1,085
20	529	374	76	89	−58	−104	1,027
Decade departure						699	−199
21	450	109	701	5	−326	−90	701
22	290	187	656	−159	−250	−258	451
23	158	309	362	−296	−131	−554	320
24	424	560	676	−34	118	−588	438
25	82	345	416	−380	−100	−968	338
26	442	160	207	−23	−287	−991	51
27	378	687	360	−90	239	−1,081	290
28	274	687	663	−197	237	−1,278	527
29	341	435	98	−133	−16	−1,411	511
30	649	76	179	172	−377	−1,239	134
Decade departure						−1,135	−893
Deficiency since first of year: gr.-cal.						3,486	475
Deficiency since first of year: per cent						9.6	1.4

TABLE 4.

Cloudiness (0—10)	0	1	2	3	4	5	6	7	8	9	10
	Gram-calories per minute per square centimeter.										
Equivalent of 0.1 inch on record sheet	0.0275	0.0275	0.0274	0.0273	0.0272	0.0272	0.0271	0.0271	0.0270	0.0270	0.0270

CORRECTION.

In the REVIEW for March, 1916, 44:113, Table 2, in the headings in place of *Mm.* insert *Cm.*

[2] *See* the REVIEW for August, 1914, 42: 478.
[3] *See* the REVIEW for June, 1915, 43: 264-266.
[4] *See* the REVIEW for August, 1914, 42: 476-480.

THE TOTAL RADIATION RECEIVED ON A HORIZONTAL SURFACE FROM THE SUN AND SKY AT MADISON, WIS., APRIL, 1911, TO MARCH, 1916.

By Professor Herbert H. Kimball and Mr. Eric R. Miller, U. S. Weather Bureau.

[Dated: Washington, May 25, 1916.]

A Callendar recording pyrheliometer[1] belonging to the University of Wisconsin was installed at the Weather Bureau Office in North Hall on April 3, 1911. The receiver is exposed on a small wooden platform on top of the instrument shelter. It is 12 feet above the roof, 71 feet above the ground, and 1,009 feet, or 308 meters, above sea level. There are no obstructions of importance between the receiver and the sky in any direction except between S. 61° W. and S. 67° W., where the dome of University Hall rises to a height of about 11 degrees and the top of the flagstaff to a height of 15 degrees. From about October 21 to November 25, and from about January 18 to February 21 the sun passes behind this dome; and for about a week preceding the first period and following the second period it passes behind the flagstaff.[2]

Considerable trouble was experienced with the Callendar register originally installed, and on July 17, 1912, it was replaced by a later type of this instrument belonging to the Weather Bureau. The record cylinder of the original register made a revolution in 24 hours. The cylinder of the new register makes a revolution in 16 hours. The time scale is 0.8 inch to the hour, and the vertical rulings on the sheet are for 10-minute intervals.[3]

The Callendar certificate for receiver No. 9864, in use at Madison, gives 0.0552 gram-calorie per minute per square centimeter as the change in radiation intensity that is represented by a lateral movement of the register pen of 0.4 cm. The longitudinal lines on the new record sheets are 0.1 inch apart. A lateral movement of the pen from one of these lines to the next, or 0.1 inch, therefore, should represent a change in radiation intensity of 0.03505 gram-calorie per minute per square centimeter. Comparisons with the Marvin pyrheliometer, which are summarized in Table 1, give a somewhat lower value than the above, except when the sun is near the horizon. These low-sun comparisons are too few in number to be given much weight, however.

Table 1.—*Comparisons of Marvin and Callendar pyrheliometers at Madison, Wis.*

Date.	Sun's alt.	*f.*	Sun's alt.	*f.*	Sun's alt.	*f.*	Sun's alt.	*f.*	Sun's alt.	*f.*	Sun's alt.	*f.*
1913.	°	*Gr.-cal.*	°	*Gr.-cal.*	°	*Gr.-cal.*	°	*Gr.-cal.*	°	*Gr.-cal.*	°	*Gr.-cal.*
Apr. 29					29.4	0.0325						
May 6	62.8	0.0347			32.7	.0350						
7	63.0	.0333										
9	63.8	.0345	43.2	0.0354								
10					31.3	.0336						
10					29.0	.0354						
1914.												
Nov. 10					28.0	0.0363						
1915.												
Mar. 26			37.9	0.0340	28.0	0.0352						
26			48.8	.0326								
26			40.8	.0345			21.0	0.0350				
27					28.9	.0369						
27			35.3	.0366								
30			38.4	.0330	29.4	.0353			15.1	0.0406		
30			49.0	.0326								
30			40.0	.0360	29.4	.0369					13.8	0.0487
July 21	57.0	0.0342	39.4	0.0327	27.4	0.332						
21	63.0	.0338										
21	59.7	.0359										
22	55.4	.0369	43.9	.0325	28.2	.0335						
Means	60.7	0.0348	41.7	0.0340	29.5	0.0349	21.0	0.0350	15.4	0.0406	13.8	0.0487

Note.—*f* is the value of 0.1 inch, or one scale division on the Callendar record sheet, in gram-calories per minute per square centimeter of horizontal surface.

The orientation of this receiver is such that a line connecting the centers of the black pair of grids lies north and south. This tends to make the intensities recorded near noon higher than they should be, and those recorded when the sun is near the horizon lower than they should be, especially during the fall and winter months.[4]

As has been pointed out by one of us,[5] it is probable that the factors obtained by comparing the Callendar pyrheliometer with the Marvin are too small by about 2 per cent for reducing records obtained when the sky is cloudless, and by nearly 1 per cent when the sky is half covered with clouds. This is because diffuse radiation from the sky is not included when the comparisons are made, and it is known that the bright grids absorb a greater proportion of short-wave than of long-wave radiation. The factor given by the Callendar certificate for receiver No. 9864 is therefore very nearly correct for average sky conditions at Madison, and it has been used in reducing all records. The reductions have been made at Madison by Mr. Miller.

In figure 1 the circles in connection with the upper curve show the maximum daily amounts of radiation that have been observed in the respective decades during the 5-year period April, 1911, to March, 1916, inclusive. This curve may therefore be considered the curve of *possible radiation* for Madison, since it represents the daily amounts that would be received throughout the year if the sky were cloudless and free from haze and smoke. During the summer months this curve is very closely in accord with a similar curve for Washington, which is drawn as a broken line in the figure. During the winter months it is markedly lower than the curve for Washington, and slightly lower than a similar curve for Mount Weather, Va.,[6] as the latitude of the stations would lead us to expect.

The circles in connection with the lower curve of figure 1 represent the 5-year means of the total daily radiation for the respective decades, after smoothing them by the formula $M = \frac{1}{3}(a+b+c)$, where b is the mean for the decade for which the smoothed mean, M, is to be computed, and a and c are the means for the preceding and following decades, respectively. During the spring months these mean values coincide quite closely with similar means for Washington, which are represented by a broken line in the figure. During the fall and winter they are considerably lower than the Washington means. Reference to the Monthly Weather Review for March, 1915, **43**: 101, figure 1, will show that the decade means for Mount Weather and Washington are quite closely in accord.

It may also be stated that during the 10 months (July, 1915, to April, 1916, inclusive) a Callendar recording pyrheliometer has been in operation at Lincoln, Nebr., the decade maxima of daily radiation at that station have generally fallen between those for Washington and Madison, as the latitude of Lincoln would lead us to expect. The decade means coincide closely with those for Washington, except during the first three months of 1916, and from August 10 to September 10, 1915, when they show an excess.

Reference to this Review for September, 1915, **43**: 440, Table 2, will show that during the fall months, when the radiation recorded at Madison is markedly deficient as compared with Washington, the maximum noon radiation intensity as measured by the Marvin pyrheliometer is also low. Furthermore, about 10 per cent more clouds have been recorded at Madison than at Washington, which would further reduce the daily averages of radiation.

[1] For a description of the Callendar pyrheliometer and the method by which it is compared with the Marvin pyrheliometer see the Monthly Weather Review for August, 1914, 42:474–481.

[2] Some further details relative to pyrheliometric exposures at Madison, Wis., will be found in the Monthly Weather Review, January, 1916, 44:2.

[3] See the Monthly Weather Review, August, 1914, 42:477, figure 5.

[4] *Miller, Eric R.* Internal reflection as a source of error in the Callendar bolometric sunshine receiver. Monthly Weather Review, June, 1915, 43: 264.

[5] This Review, August, 1914, 42: 476–480.

[6] See the Review, August, 1914, 42: 484, figure 8.

Column 3 of Table 2 gives the proportional deficiency of maximum daily amounts of radiation in the fall as compared with the maximum amounts in the spring when the sun has the same declination. Column 4 gives similar data with reference to the daily means. These latter show a greater seasonal variation than was found at Washington. The last column of Table 2 gives the percentage of possible radiation obtained at Madison at different seasons of the year. During the warm months the percentage is slightly less than at Washington, and during the cold months it is slightly greater.

Radiation deficiency during crop season, 1915.

With reference to the records from year to year, the most remarkable feature is the deficiency in radiation during the crop-growing season of 1915. From May 1 to August 10, inclusive, which was a period of excessive cloudiness, the deficiency in radiation was 7,253 gram-calories per square centimeter, or 14 per cent of the average, while from May 1 to September 30, inclusive, it was 7,595 gram-calories, or 11 per cent of the average. From May 1 to August 31, inclusive, the average daily

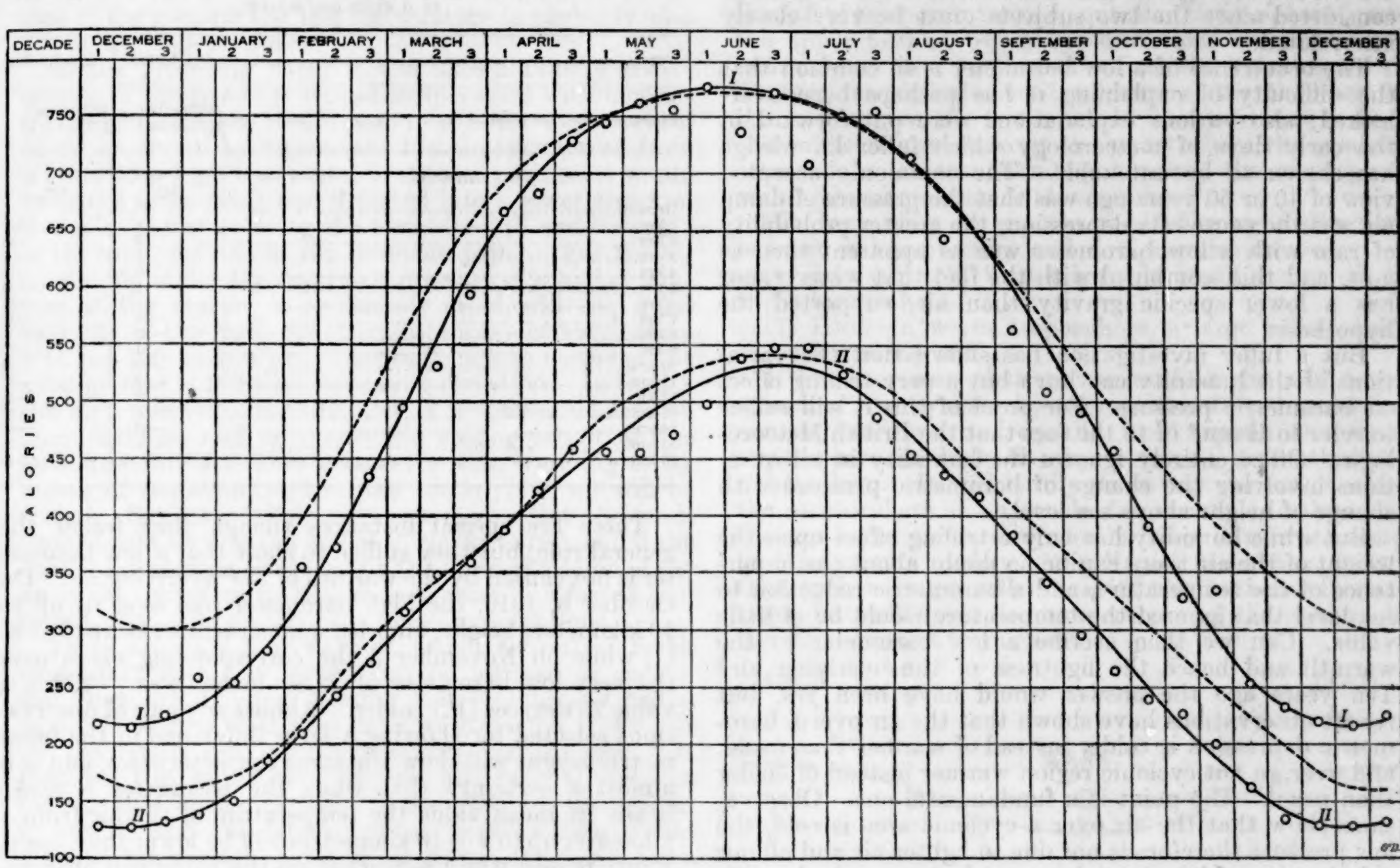


FIG. 1. Maximum (I) and mean (II) daily amounts of solar and sky radiation in gram-calories per square centimeter of horizontal surface. Solid lines, Madison, Wis.; broken lines, Washington, D. C.

TABLE 2.—*Seasonal relations of radiation intensities at Madison, Wis.*

Dates.	Solar declination.	Ratios: Max./Max.	Mean/Mean	Dates.	Ratios, Mean/Max.
Oct. 27 / Feb. 15	° −13	0.88	0.86	Feb. 15 Mar. 21	0.65 0.59
Autumnal equinox / Vernal equinox	± 0	0.88	0.93	Apr. 15 June 21 Aug. 27	0.59 0.69 0.63
Aug. 27 / Apr. 15	+10	0.90	0.97	Sept. 21 Oct. 27 Dec. 21	0.63 0.63 0.59

temperature deficiency for the State of Wisconsin was 4.5 degrees (F.)[7]

Of the remaining years, the last half of 1912 received relatively a small amount of radiation. The distinguishing feature of this period, however, and also of the year 1913, is the low value of the maximum daily radiation, or the radiation received on cloudless days. These low values may doubtless be attributed to the haziness of the upper layers of the atmosphere following the eruption of Katmai volcano in Alaska in June, 1912. The diminished intensity of direct solar radiation during this period, as shown by measurements with the Marvin pyrheliometer, has been referred to in a previous paper.[8]

[7] See "Condensed Climatological Summary," this REVIEW, May to August, inclusive, 1915.

[8] This REVIEW, January, 1916, 44:8.

THE LOCAL CIRCULATION OF THE ATMOSPHERE.

By WILLIAM HENRY DINES, B. A., F. R. S.

[Dated: Meteorological Office Observatory, Benson, Wallingford, England, Mar. 29, 1916; received Apr. 22, 1916.]

In the November, 1915, number of this REVIEW[1] certain difficulties connected with the general circulation of the atmosphere and the distribution of temperature therein were pointed out. The local circulation, the passage of cyclones and anticyclones over a locality, with the accompanying changes of weather, ought also to be considered since the two subjects must be very closely interrelated.

The occurrence of a low barometer is so common that the difficulty of explaining it has perhaps been overlooked; also various explanations were put forward in the early days of meteorology which fuller knowledge has shown to be untenable. The commonly accepted view of 40 or 50 years ago was that the pressure of damp air was the cause of a depression; the greater probability of rain with a low barometer was as apparent then as now, and this, combined with the fact that water vapor has a lower specific gravity than air, supported the hypothesis.

But a fuller investigation has shown that the variations of the humidity can have but a very trifling effect on barometric pressure. For proof of this it will suffice to refer to Hann,[2] or to the fact that the British Meteorological Office entirely ignores the humidity in all questions involving the change of barometric pressure with change of height above sea level.

But while humidity has only a trifling effect upon the weight of the air there can be no doubt about the importance of the temperature, and a barometric reduction to sea level that ignored the temperature would be of little value. Can we then ascribe a low barometer to the warmth and hence the lightness of the overlying air? Ten years ago the answer would have been yes, but recent observations have shown that the air over a barometric depression is colder instead of warmer than usual, and over an anticyclonic region warmer instead of colder than usual. The point is a fundamental one. Observations show that the air over a cyclonic area is cold, the low pressure therefore is not due to lighter air and all our old theories which seemed so satisfactory and plausible have been upset. One's first feeling is to doubt the accuracy of the observations, and it is desirable to examine the evidence. There is no great difficulty; it is simply a matter of expense and a moderate amount of skill, in sending up a light meteorograph hanging from a small free balloon with a label attached offering a reward for the return of the meteorograph. The practice has been carried on systematically at many stations in Europe for 10 years at least, with the result that a thousand or perhaps more observations have been published giving the values of the temperature, and in many cases the humidity, from the ground upward to about 15 and in some cases to 20 km. (9-12 miles). The instruments used in the British Isles are different from those used on the Continent and the system of calibrating is different, but the results are practically identical. The British Isles are subject during the winter months, to a continual succession of deep depressions passing along their western coasts and they are in consequence a very suitable locality for the study of cyclones and anticyclones. The figures given in Table 1 below refer to the British Isles simply for this reason: Observations there at times of very low barometer, 29 inches or so, are more numerous than on the Continent, but were there no observations at all from England the Continental observations would amply suffice to show the coldness of the cyclone and the warmth of the anticyclone.

To show the contrast between the temperatures in a cyclone and in an anticyclone the following special cases are given from observations made at Pyrton Hill in 1910. Pyrton Hill is some 40 miles west-northwest of London.

TABLE 1.—*Vertical temperature distribution at Pyrton Hill, England, in a* HIGH *and a* LOW.

Dates	Oct. 6, 1910.	Nov. 3, 1910.
Pressure, mean sea-level	1029 mbar. (30.30 in.)	979 mbar. (28.78 in)
ALTITUDE.	°C.	°C.
Ground	16	5
1 km	13	−1
2 km	12	−4
3 km	7	−9
4 km	0.5	−15
5 km	−5	−24
6 km	−11.5	−31
7 km	−18	−39
8 km	−26	−42
9 km	−34	−42
10 km	−43	−44
11 km	−52	−43
12 km	−59	−45
13 km	−66	−45
14 km	−66	−48
15 km	−66	−50
16 km	....	−49

These are special instances though they follow the general rule, but they suffice to show that a low barometer is not caused by the warmth of the overlying air. On October 6, 1910, the high barometer had over it, up to 10 kilometers height, air with a mean temperature of −8° C., while on November 3 the corresponding mean over the very low barometer of 28.80 inches was −22°C., a value 25 degrees (F.) colder. Almost any pair of observations selected for showing a large difference in the barometric height will show the same characteristics, and it is almost a certainty that when the barometer is much below its mean value the temperature of the air from 1 kilometer up to 8 or 10 kilometers will be lower than usual. Every person who has worked up the European observations has come to this conclusion.

In Table 2[3] the most probable values of the temperature in the British Isles at times of low and of high barometer are given in the absolute, centigrade and Fahrenheit scales.

TABLE 2.—*Probable temperatures over the British Isles in a* HIGH *and in a* LOW.[3]

Height.			Cyclone.			Anticyclone.			Difference.
Kms.	*Miles.*	*Ft.*	°*A.*	°*C.*	°*F.*	°*A.*	°*C.*	°*F.*	°*C.*
1	0.62	3,300	276	3	37	279	6	43	−3
2	1.24	6,600	270	−3	27	276	3	37	−6
3	1.87	9,900	263	−10	14	271	−2	28	−8
4	2.49	13,100	256	−17	1	265	−8	18	−9
5	3.11	16,400	249	−24	−11	259	−14	7	−10
6	3.73	19,700	242	−31	−24	253	−20	−4	−11
7	4.35	23,000	234	−39	−38	246	−27	−17	−12
8	4.97	26,300	228	−45	−49	238	−35	−31	−10
9	5.59	29,600	226	−47	−53	231	−42	−44	−5
10	6.21	32,800	225	−48	−54	225	−48	−54	0
11	6.84	36,100	224	−49	−56	220	−53	−63	4
12	7.46	39,400	225	−48	−54	217	−56	−69	6
13	8.08	42,700	225	−48	−54	215	−58	−72	10
14	8.71	46,000	224	−49	−56	215	−58	−72	9
Value of H_c.			8.7 *km.*			12.3 *km.*			3.6 *km.*

[1] MONTHLY WEATHER REVIEW, Nov., 1915, 43: 551-556.
[2] *Hann, J.* Lehrbuch der Meterologie, 2d edit., 1906, p. 612.

[3] This table is taken from the Journal of the Scottish Meteorological Society, 1914, 16, No. 31.

Now it is plain from these figures that we can not explain a low pressure area by the warmth and smaller density of the air above it. There must be, of course, a smaller mass of air above it, but the greater part of that mass has a lower temperature and therefore a higher density than usual. Just the same difficulty occurs in the question of the general circulation, for in the Southern Hemisphere over the latitude belts of 50°-60° S. the pressures are very low and the air temperature is also low. In both cases the explanation must be that the low pressures are due to dynamical causes and in the case of the cyclone the low temperature is probably also due to dynamical causes.

In the preceding paper it was shown that in consequence of the rise of potential temperature with increasing height the air would strongly resist any vertical motion. But if by any means the air were forced from a lower to a higher stratum, in its new position it would be found to be cold; and if forced into a lower stratum, it would be warm; using the terms "cold" and "warm" in the sense defined in the previous paper. For the air on coming under the decreased pressure of a higher stratum, if the motion is sufficiently rapid, will cool adiabatically at the rate—for short distances—of very nearly 1°C. per 100 meters and this gradient is in excess of the average rate of fall with increasing elevation. In reality the air's motion is usually slow, a few hundred feet an hour perhaps, and no doubt the cooling is not at the adiabatic rate for there is time for some warming up by means of radiation; still on the whole rising air will be cooled. Similarly falling air is warmed. But the tendency of cold air is to fall and of warm air to rise, and if the cold of a cyclone is produced by the upward motion of the air in the central parts that motion must be a forced one, forced, that is to say, by the pressure conditions.

There are only two ways in which air out of reach of contact with the ground can be warmed or cooled, and they are dynamic heating and cooling and radiation. It is true that heat may be imparted to the air by the latent heat of condensation, but we need not consider this point here because we have to account for the cold of the cyclone at the altitudes where rain is formed and the latent heat of condensation would account for warmth, but not for cold. We know for a fact that the air in a cyclonic area has a tendency to rise; it is proved by the inclination of the surface winds to the isobars and by the tendency to rain, since rain in any volume can only be caused by an ascending current; and we have the choice of two ways of accounting for the coldness of the rising air, one by dynamic cooling due to the rise which involves a pushing or sucking upward of the air, the other by radiation. If we accept the hypothesis of radiation, we must show that cyclonic conditions specially favor the loss of heat by radiation from the air at altitudes between 2 and 8 kilometers, and we must also explain why the air so cooled by radiation does not sink as one naturally would expect it to do.

Before discussing this point it will be well to see what happens at greater heights over the cyclone and over the anticyclone. Above some 10 kilometers the conditions of heat and cold are reversed. Thus at 7 kilometers (see Table 2) the cyclone is 12° C. colder than the anticyclone, but at 13 kilometers the conditions are reversed and it is 10° C. warmer. In a cyclone the fall of temperature with increasing height is very rapid in the lower strata, but it ceases at about 9 kilometers; in an anticyclone the fall per kilometer is not large to begin with, but it strengthens higher up and is continued to about 12 kilometers. In both cases the temperature gradient ceases suddenly at heights of about 9 to 12 kilometers. This is well shown in the two records given, and is a fixed rule with very few exceptions. The sudden cessation of the loss of temperature with height is not markedly shown in the mean values, because it does not always occur at the same height. This height is very commonly denoted by H_c and its mean value is given at the foot of Table 2.

This sudden cessation was discussed by Teisserenc de Bort, the well-known French meteorologist, and he proposed to call the lower part of the atmosphere in which the fall of temperature is present, the "troposphere"; and the upper part in which the conditions are isothermal, or nearly so, in a vertical direction, the "stratosphere". There is no definite word to express the thickness of the troposphere H_c, but it would be convenient to have one. The temperature at the point where the gradient ceases, i. e., at the boundary between the troposphere and stratosphere may be denoted by T_c.

We have then to explain the following distinctions between a low-pressure and a high-pressure area:

(1) LOW = a cold troposphere, a small value of H_c and a high value of T_c.

(2) HIGH = a warm troposphere, a large value of H_c, and a low value of T_c.

It has been seen that we can explain the cold troposphere of the cyclone by means of a forced ascending current, and we can equally well explain the warm stratosphere (a high T_c) by a forced descent in the stratosphere. It will hardly do to say current, because the stratosphere is so stable for vertical displacement that no current can occur, but a bulge downward seems to form over a cyclone. Sir Napier Shaw has shown[4] that such a bulge will not alter the isothermal conditions, but will raise the temperature of the column by the same amount throughout.

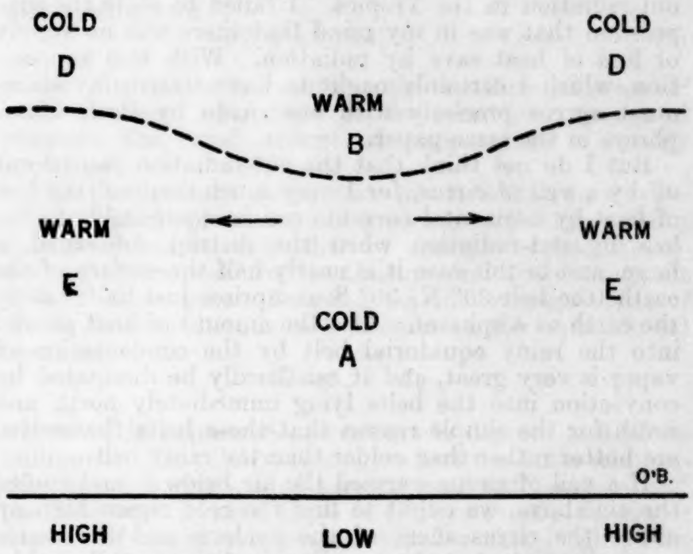


FIG. 1.—A vertical section through a LOW between two HIGHS.

Suppose the diagram, figure 1, to represent a vertical section through a low pressure placed between two anticyclones and remember that the horizontal and vertical scales are of necessity different in all such cases.

The terms "cold" and "warm" indicate departures from the average values for the height and are found almost without exception in every cyclone and anticyclone in which observations have been made. The

[4] *Shaw, W. N.* Note on the perturbations of the stratosphere. *In* The free atmosphere in the region of the British Isles. Meteorological Office, London, 1909. Publication No. 202. pp. 47-52.

temperatures close to the ground are uncertain, for they depend on the direction of the wind, on the time of day, and other things, but the indications in the diagram hold from 1 kilometer up to 20 kilometers, beyond which height we have practically no information. The dotted line denotes the boundary at which the fall of temperature with height ceases.

About three-quarters of the atmosphere is found below the dotted line and though the upper part over the LOW is warm the chief part, A, is cold; on the whole, therefore, the air is cold, and the explanation that a low pressure is caused by warmth fails utterly. The low pressure must be caused by the strength of the winds which encircle it and their tendency to draw the air away from the central parts, partly by their centrifugal action, but probably in temperate latitudes chiefly by their tendency to turn to the right on account of the rotation of the earth.

Now if the temperatures are due to dynamic causes they may be explained thus: We have seen that air that is being forced upward is cold and that air that is being forced downward is warm. If the winds are strongest at 8 or 9 kilometers, they will exert a sucking action away from the center at that height, as shown by the arrows; air will be drawn up in the region A until its coldness and weight prevent any further rise; it will sink in the region E until its warmth stops any further fall; the stratosphere will be drawn down under B and raised under D, as we find it to be by actual observation. This will be more fully explained further on.

The alternative is to explain the temperatures by radiation, and I do not see how this can be done. In my previous paper the editor very kindly, by a footnote, called my attention to a paper by Prof. Humphreys which apparently contradicts my statement about the out-radiation in the Tropics. I failed to state the supposition that was in my mind that there was no supply or loss of heat save by radiation. With this supposition, which I certainly ought to have stated, my statement agrees precisely with one made by Prof. Humphreys in the same paper.

But I do not think that the out-radiation can be cut off by a veil of cirrus, for I very much doubt if the loss of heat by horizontal currents can be comparable to the loss by out-radiation when the district concerned is large, and in this case it is nearly half the surface of the earth (the belt 30° N.–30° S. comprises just half, taking the earth as a sphere). Also the amount of heat poured into the rainy equatorial belt by the condensation of vapor is very great, and it can hardly be dissipated by convection into the belts lying immediately north and south for the simple reason that these belts themselves are hotter rather than colder than the rainy belt.

If a veil of cirrus warmed the air below it and cooled the air above, we ought to find the cold region high up above the cirrus sheet of the cyclone and the warm region below it, but the opposite condition usually holds. Though cirrus cloud is not confined, at least in England, to areas of low pressure, it is certainly more common in such areas, for it is not at all frequent in anticyclones.

In the previous paper it was stated that the pressure at some 8 or 9 kilometers height ($5\frac{1}{2}$ miles) dominated all the other elements, and no account of our present knowledge of the local circulation can be at all complete without giving the grounds on which this statement is made. It is based on a statistical analysis of the European observations.

To attain to a complete knowledge of the local circulation we require to know the temperature, pressure, and humidity, also the velocity and direction of motion, of the air at each height, say in steps of 1 kilometer, over a considerable area. It is likely enough that there is some definite connection between some of these quantities, so that if two or three of them were known the rest might be known. The statistical method of correlation affords the means of ascertaining the nature of such connections, and it has been applied somewhat extensively to simultaneous pressures and temperatures of the air in a vertical direction, and to a less extent to the humidities and direction of motion. The following is a brief account of the results, some of which have been published [5] and some not.

As already stated, the pressure at 9 kilometers (in future for the sake of brevity denoted by P_9) seems to be the dominant factor—that is to say, that if P_9 is known, then the other pressures and temperatures are fairly well known. No other variable serves to give us so good a knowledge of the general conditions between 12 kilometers and 20 kilometers as this. If we knew that on a certain date the barometer at London stood at the low value of 29 inches, we should expect to find the temperature of the lower air column (from 1 to 9 kilometers) 8 degrees (C.) colder than usual and the thickness of the troposphere, H_c, 3 kilometers less than usual. These values would be guesses more or less, but it would be a practical certainty that both quantities would be below their average value. If, however, we knew the value of P_9 on that date, we could make a better guess at the temperature and at the value of H_c, because these quantities depend more on P_9 than on the surface value of the barometer.

It may be stated broadly that all the temperatures from 1 kilometer up to 20 kilometers, and probably much higher, are closely connected with P_9. The surface temperature is likely to be a little higher than usual when P_9 is high, but the connection is not a close one. The surface temperature seems to be dependent on the direction of the wind and other elements and is not closely correlated with any other quantity.

First, the P_9 is very closely connected with the temperature of the air in the column from 1 kilometer to 9 kilometers, the correlation coefficient, r, being nearly 0.90. The P_9 is calculated from the barometric reading at mean sea level and the mean temperarure from 0 to 9 kilometers, so that there must in any case be a close connection, but the actual connection is much closer than it would be if the temperature were purely fortuitous.

Secondly, the P_9 is closely connected with the thickness of the troposphere, H_c, the correlation reaching about $r=0.80$.

Thirdly, the mean temperature from 1 kilometer to 9 kilometers is of necessity highly correlated with the thickness of the troposphere, H_c, because both are closely connected with P_9. The correlation coefficient is about 0.75. The connection might be direct, but treating the figures by the method of partial correlation it appears that the connection is not a direct one, for if the influence of P_9 is excluded then there is no connection between the quantities.

It may be stated that a correlation coefficient is a numerical measure of the connection between two quantities; it must lie between +1 and −1. It gives the connection as it is shown by the given set of

[5] Meteorological Office No. 210b. Geophysical Memoir No. 2. Beiträge zur Physik der freien Atmosphäre. v. 5, pt. 4.

observations and is quite reliable when the number of observations on which it is based is large. A value of + 1.00 or − 1.00 shows perfect proportionality between the quantities, values of 0.70 or above show a close connection, and values below 0.25 or so are not significant. As a guide it may be said that the correlation coefficient between the closeness of the isobars and the strength of the wind is about 0.70.

The three instances given are the three closest connections that so far have been discovered between variable quantities in the upper air, but there are several others with correlation coefficients between 0.40 and 0.70. The fact is that the hopeless complexity that prevails at the surface is absent as soon as a height of a few thousand feet (1 km.) is reached. These connections are:

(1) Between P_9 and the surface pressure, $r = 0.65$;
(2) Between H_c and the surface pressure, $r = 0.65$;
(3) Between H_c and the temperature of the stratosphere, i. e., between H_c and T_c, $r = -0.65$.
(4) Between the surface pressure and T_c, $r = -0.50$;
(5) Between the mean temperature 1 to 9 kilometers and the surface pressure, $r = 0.45$;
(6) Between P_9 and T_c, $r = -0.45$.
(7) To these must be added a connection between the total amount of water vapor in the air and the mean temperature of the lower layers (0 to 5 km.), r is about 0.65. This result is curious, for the anticyclone has from 1 to 5 kilometers a high temperature and a low relative humidity; the explanation is that warm air can hold so much more vapor than cold, that warm air even when dry in an anticyclone carries more water than the wet cold air of a cyclone.[6]

That the air in summer notwithstanding its dryness contains far more moisture than in winter is well known to most meteorologists.

It hardly seems likely that there are many more close connections in the atmosphere beyond those enumerated above, but there are a few other weak connections with correlation coefficients of 0.20 to 0.30 that may be stated. The temperature near the surface is colder with a north or northeast wind, but the effect does not extend to beyond 4 or 5 kilometers. The value of H_c is lower with a barometric gradient favorable for north winds. The value of H_c is lower when the barometer has been rising for 12 hours than when it has been falling. Perhaps these last two statements represent the same phenomena, for a rising barometer generally accompanies a northerly gradient. They are fairly well established, but the effect is not large and it is just possible that they are due to a large casual error.

There are also three negative results that must be stated. Save at low levels the direction and strength of the wind has no effect upon the temperature. The value of H_c is not directly influenced either by the temperature or by the total water content of the lower air column.

Each of the above results is based on the statistical treatment of at least 200 observations, so that it is fairly reliable and we are able to draw a fairly accurate picture of the changes that are in progress in the upper air as a HIGH or LOW passes. As the pressure falls the air temperature from about 1 up to 9 or 10 kilometers becomes colder, the pressure up to the same height decreases by about the same amount as at the ground. Above 12 kilometers the temperature rises and a downward bulge of the stratosphere is formed which with a really deep depression may reach down to within 8 or even 7 kilometers of the ground.

In this upper part of the atmosphere the defect of pressure tails off rapidly not only in actual magnitude but as a percentage of the whole, until at 20 kilometers or a little over, equality of pressure between cyclones and anticyclones seems to be reached. It is at about this height that equality between the pressure over England and over the Equator is found.

The converse occurs with a high barometer. As previously stated we have the choice of two ways for explaining the peculiar distribution of temperature and the change of H_c, for the value of H_c—the thickness of the troposphere—is an essential part of this distribution, since it measures the height to which the fall of temperature with height extends. The view that H_c, so far as its variation between high and low pressure areas is concerned, is dependent on radiation seems to me quite untenable for the following reasons:

The out-radiation on which it is said to depend must itself be dependent on the temperature and radiative power of the lower strata. The radiative power undoubtedly varies with the amount of water vapor, but the statistical investigation shows that neither the temperature nor the water vapor of the air has the slightest effect upon H_c. Therefore H_c can not be dependent on radiation. Still stronger, perhaps, is the following argument. Changes in temperature of 10 degrees (C.) may occur in 24 hours, and such changes can not be due to radiation because if the whole solar heat received per day were devoted to warming up the atmosphere it could only warm it about three degrees (C.). Radiation is therefore incapable of changing H_c as rapidly as it is known to change under the changing pressure conditions.

On the other hand if we suppose that changes of pressure at about 9 kilometers height, i. e., changes in P_9, are the cause of the phenomena, there is no difficulty about explaining the other changes. Changes of temperature that are adiabatic occur simultaneously with the changes of volume which produce them and are in accordance with the formula

$$\delta T/T = 0.29\,\delta P/P, \qquad (1)$$

where T is the temperature on the absolute scale and P is the pressure. If, therefore, we accept the change of pressure, the rapid change of temperature is readily explained.

The temperature changes are produced in two ways—one by the simple change of pressure of the air without change of height; the other by changes of height produced by the pressure distribution and the consequent change of pressure. Substituting the average value of T and P at an altitude of 9 kilometers, the equation (1) becomes

$$\delta T = 0.22\,\delta P,$$

where δT is expressed in centigrade degrees and δP in millibars. The observations give just the same relationship between changes of pressure and temperature, and the inference is that there is no systematic ascent or descent of air at this height.[7] Below this height, that is to say, in the troposphere, the change of temperature is in excess of the value given by the formula; and above in the stratosphere, it is of the opposite sign; but how this may be brought about has already been explained.

It remains to show how these vertical motions may be produced. Let us take the conventional section through a cyclone presented in figure 2, remembering, however, that it can not be drawn to scale on any moderate sized piece of paper. Also there need be no symmetry about the horizontal section or plan; all that is necessary is that the low pressure should be inclosed by a set of closed

[6] Some quantitative measurements here would be interesting; also a consideration of clouds and depths of moist air.—C. A. Jr.

[7] *Shaw*, Sir *Napier*, in Jour. Scott. met'l soc., No. 30, 16: 177.

isobars; they need not be circular—their shape is quite immaterial.

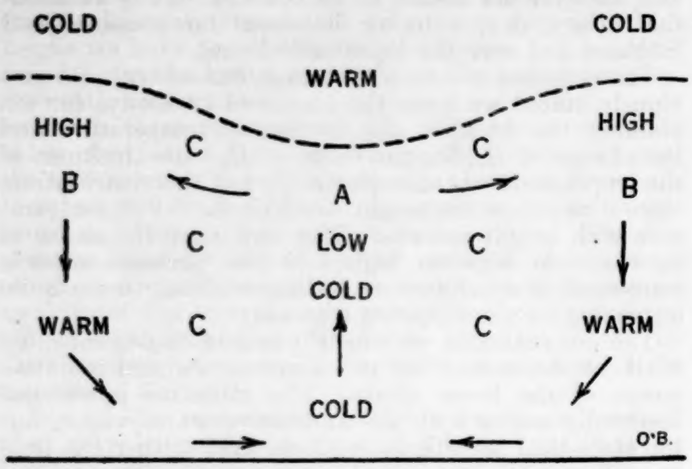


FIG. 2.—A conventional vertical section through a LOW.

Now, suppose that the inception of the system is brought about by a decrease of pressure in the region A and that the decrease is brought about by the strengthening of the winds in the region CC. In my previous paper [8] it was shown how, in the Northern Hemisphere, a wind had the low pressure on its left hand; hence the wind at C must be taken as blowing at right angles to the paper, away from the eye on the right-hand and toward it on the left. The result is a lower pressure at A than at B, and the natural tendency is for air to flow from B to A. In the middle regions the direct way is barred by the acceleration of the winds away from A, but in the diagram as drawn there is nothing to prevent air passing from B to A either above or below the region C. Consider the upper path first. The winds fall off in velocity in the stratosphere, as Mr. Cave and others have shown, so that there is no obstacle on account of their acceleration toward the right hand; but the stratosphere is so stable that any vertical current is strongly resisted, and probably very little air passes back above C from B to A. But we may probably take the stratosphere to consist of almost the same air, with very little interchange with the troposphere, and that being so it is naturally forced upward over B and drawn downward over A, with the result as regards the temperature that is shown. In figure 2 the position of its lower boundary is shown by the dotted line. The dynamical explanation therefore accounts for the very close connection between P_9 and H_c.

Now let us consider the lower path from B to A. It is probable that the air as it endeavors to reach A gets turned to the right by the earth's rotation and simply extends the region C downward, and that this continues till C extends nearly to the earth. If we count C as the region in which the wind is parallel to the isobars it can not quite reach the earth, because the friction, including what has very aptly been called "convectional friction" prevents the actual surface wind from being as strong as the gradient wind. Its acceleration outward can not balance the pressure gradient, and the surface wind, as is well known, blows inward at an angle of 20° or 30° with the isobars. Air can therefore pass from B to A by going first downward under B, then moving inward slowly—the friction of the surface prevents any rapid movement—and then rising under A. This process explains the curious distribution of temperature that is found both above and below.

[8] MONTHLY WEATHER REVIEW, November, 1915, 43: 552.

Thus all the close relationships between pressure and temperature that have been discovered, probably all that exist, can be explained on simple dynamic principles if we start with the supposition that the disturbance begins at 8 or 9 kilometers and then spreads downward, producing the surface phenomena that we know so well.

How the upper winds that encircle a certain region come into existence, strengthen themselves, or die away, is not clear; neither is the process which secures a sort of rough equilibrium between the pressure gradients and the winds, but the strongest winds are certainly prevalent in the upper half of the troposphere. However a low pressure is produced, it certainly is not due to the high temperature of the air above it; that is to say, it is not a convectional effect produced by the juxtaposition of hot and cold air.

THE PLANETARY SYSTEM OF CONVECTION.

By WM. R. BLAIR, Professor of Meteorology.

[Dated: Weather Bureau, Washington, May 11, 1916.]

Unequal heating of the air over a given area resulting from topography, from the distribution of land and water and of vegetation, or from a combination of these gives rise to local systems of convection. Other local systems are more or less mechanically caused. A current of air, relatively heavy when compared with air at the same level, undergoes change of speed and cross section, especially in its lower levels, in order to adapt itself to the topography of the bottom—solid, liquid, or aerial—over which it flows. These changes in rate and cross section are accompanied by changes in temperature, pressure, and by more or less change in direction of air movement. The changes may be small, but a study of many of these indicates that every gust of wind has all the attributes of a full-fledged system of convection and differs from other systems primarily in extent and duration only. Other systems of convection, the diurnal system and the planetary system, owe their existence to unequal heating, but in these cases the unequal heating is directly related to the relative positions of the earth and sun. The high and low pressure areas that move from west to east in the middle latitudes are apparently directly related to the planetary system of convection and will be considered again later.

Probably Ferrel more than any other has contributed to our comprehension of the planetary system of convection. Some of the principles formulated by him in connection with his study of this system are still considered as fundamental as ever. The law of equal areas, when we consider with it cross section and air density in the case of an air current, and the law of deflection to the right of air or other material in motion, because of the earth's rotation, are still to be given primary consideration. Since these studies by Ferrel were made many new data have been obtained. Observations have been made at higher latitudes and at higher levels than were then attainable. The abundance and range of these observations seem to justify a sort of reconstruction of the Ferrel conception of the planetary circulation. This conception has been generally accepted and is still found in the textbooks. It is well founded, but, reconstructed, it seems to be more complex than as first conceived.

The free-air observations available for the purpose of this paper are distributed about as follows: In tropical latitudes observations to considerable heights have been made in the Dutch East Indies and in Africa; about latitude 40° N. in the United States; from 40° to 60° N.

many excellent observations have been made in Europe and in Canada; for higher latitudes the observations made in Greenland, Spitzbergen, and in the Antarctic Continent have been used. While many data are thus available, many have been obtained in recent years that are not available, because they are not yet published or have not yet reached us. Only data published in sufficient detail to permit of their intercomparison with reference to the subject in hand have been used. These data, from whatever source, fit together remarkably well and the facts stated in the first part of this paper seem to be well substantiated, all available observations considered.

Observations in the upper tropical and lower middle latitudes would fill a rather wide gap and be of great assistance in any consideration of the general circulation. If, in addition to these, observations to great altitudes could be obtained at very high latitudes, the meridional distribution would be fairly complete. Observations in which the speed and direction of air movement, in addition to air temperature, pressure, and humidity, are obtained for all levels are especially valuable.

In the review of observations which follows, more space is given to the observations at high levels and high latitudes than to surface observations in the middle and lower latitudes, not that these are of more importance to the conception of the planetary system of circulation as a whole, but because they are the newer and less familiar data to be considered.

OBSERVATIONS OF AIR MOVEMENT.

In the series of free-balloon ascensions made at Fort Omaha in July, 1914,[1] there were three cases in which the balloon was followed with two theodolites to heights of 20 kilometers or above. In each of these cases the balloon in its ascent experienced differently directed winds for the first few kilometers above the earth's surface. Above this stratum it passed through a steady westerly wind with maximum velocity at the 12 to 15 kilometer levels. Between the 16 and 17 kilometer levels the balloons passed from the westerly wind into an easterly wind which increased with altitude from low to high velocity.

In looking over previous records three other ascensions are found in which the balloons were followed with one theodolite to the 20-kilometer level or above. Two of these three were made in July, 1913, at Avalon, Santa Catalina Island, Cal. The third was made in September, 1910, at Huron, S. Dak. The two July ascensions show practically the same phenomena at high levels above Avalon as are shown above Fort Omaha by the ascensions of July, 1914. In the ascension at Huron, made farther north and later in the year, the balloon did not experience the upper easterly wind, although it was observed to a height of 26.8 kilometers. At this height the wind was still westerly, but its velocity was low, 1.1 meters per second.

Of the six ascensions, the balloon in that of July 9, 1914, was observed to the greatest height, 31.6 kilometers. At this height the easterly wind had a speed of 19 meters per second. A noticeable fact in connection with this ascension is the persistence of the north component in the air movement to the highest levels at which observation was made. Figure 1 shows the horizontal projections of the paths taken by the balloons in the six ascensions to which reference has been made. It will be noted that, in each of the five cases showing an easterly wind above the 17-kilometer level, the north or south component prevailing in the westerly wind below the 16-kilometer level persists in the upper easterly wind. This north or south component does not necessarily obtain in the surface or variable wind stratum. The north or south components have maximum values in the upper westerly and in the upper easterly winds. Their values may be zero in the comparatively quiet air between these two currents.

Reviewing the free-air data obtained by other observatories, especially those obtained at great altitudes, it is found that in higher latitudes the upper easterly wind has not yet been observed. The balloons sent up in the higher latitudes have passed through the upper westerly winds into the region of comparatively quiet air. The upper easterly wind has been observed in the lower latitudes, but here it is found immediately above the upper westerly wind. The region of quiet air between these two currents, which has been found in the middle and higher latitudes, is very shallow, if it may be said to exist at all, over the Tropics. Over the Tropics the upper westerly winds are found at about 20 kilometers above sea level and are approximately 5 kilometers in depth. Above them the wind is easterly. The upper limit of the easterly wind has not been reached in the lower latitudes, but a maximum velocity of 40 meters per second has been observed at the 29.5-kilometer level, the velocity at the 30.5-kilometer level being at the same time 34 meters per second. The upper westerly wind is found to begin at lower levels and to be deeper in the middle and higher latitudes than over the Tropics. From a depth of 4 or 5 kilometers over the Tropics this current increases to a depth of 10 or 12 kilometers at 35°–40° north latitude. Observations of its depth at very high latitudes are not yet available.

Below the upper westerly winds in the Tropics are found in the order of their height: The trade winds, extending from the earth's surface to a height of 3 to 5 kilometers; the antitrades, extending from the 3–5-kilometer up to the 15–17-kilometer levels; the upper trades, lying between the antitrades and the upper westerly wind.

In the upper tropical and lower middle latitudes and between the antitrade and upper trade winds is found a region of comparatively quiet air similar to that found between the upper westerly and the upper easterly winds, but not so extensive. The observations upon which this statement is based are those on the movement of upper clouds in the United States south of about 35° north latitude. The motion of these clouds is indifferent in the summer months. When motion is evident it is as likely to be from the east or south as it is to be from the west or north. In the winter months the upper clouds over this territory move decidedly and from a westerly direction. This is taken as indicating that this region of light winds or calms moves north and south with the sun. Unfortunately no aerial soundings have been made in the southern United States nor have the cloud altitudes been observed together with the cloud movement. The extent and velocity of the easterly winds just above the comparatively calm region at about the cirrus level in these latitudes has not therefore been directly observed. East winds at the 10-kilometer level have, however, been observed as far north as Omaha and Indianapolis, but only occasionally.

Below the upper westerly wind in the middle latitudes is found a stratum in which differently directed winds blow. The resultant air movement in this stratum, as

[1] The results of this series of balloon ascensions will appear in this REVIEW, May, 1916.

observed at Mount Weather, Va., is from the west at rates varying with altitude from 3.5 meters per second near the earth's surface to 19.7 meters per second at the 4-kilometer level. Two maxima of wind frequency are found at the earth's surface. These are southeast and west-northwest to northwest. These two maxima converge toward the west with altitude, being south and

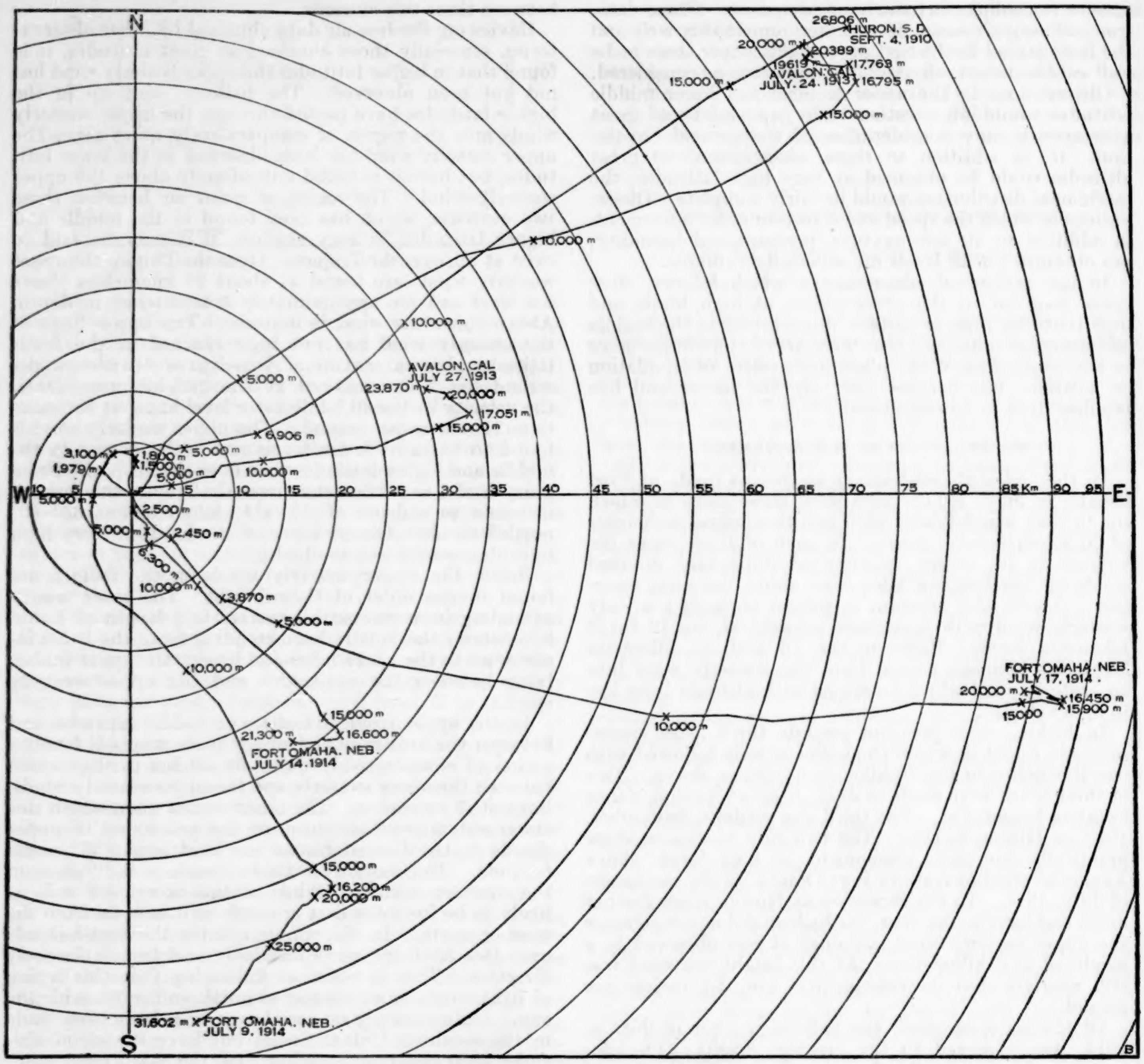


Fig. 1.—Horizontal projection of sounding balloon paths.

west-northwest to northwest at the 1-kilometer level, and southwest and west-northwest at the 2-kilometer level. But one maximum of wind frequency, from west to west-northwest, is found at the 3- and 4-kilometer levels. In the polar regions, bounded by small circles at approximately 60° north and south from the thermal equator, an anticyclonic condition about the poles tends to prevail below the upper westerly wind. The easterly winds resulting from this anticyclonic condition are shallow, usually less than 1 kilometer in depth. The polar anticyclonic conditions are better developed in the cold than in the warm half of the year and, because of uniformity of surface about the South Pole, seem to be better developed there than about the North Pole.

OBSERVATIONS OF TEMPERATURE.

Many observations of the temperature-altitude relation have been made at Mount Weather by means of kites and captive balloons and in the middle and far West of the United States by means of sounding balloons. As shown by these observations, this relation varies greatly

from time to time in the lower 2 or 3 kilometers of the atmosphere, is fairly uniform and constant from the 3 to the 11 or 12-kilometer level, has a small value from the 11 or 12 to the 15 or 16-kilometer level, is negative[2] from the 15 or 16 kilometer level to the 28-kilometer level, is still negative, but of decidedly smaller value, from the 28 to the 32-kilometer levels. The value of the relation in the lowest stratum above defined may be anything from more than the adiabatic rate to a strongly inverted condition; in the second stratum about 6.5°C. per kilometer; in the third, 1°C. per kilometer or less; in the fourth, −1.7°C. per kilometer; and in the fifth, −0.3°C. per kilometer. This relation is fairly well shown in figure 2, which represents a mean of three observations, each to a height of more than 30 kilometers above sea level. The three observations considered were all made in the summer half of the year: One at Huron, S. Dak., September 1, 1910; one at Avalon, Cal., July 30, 1913; and one at Fort Omaha, Nebr., July 9, 1914. They should be considered as characteristic of the position they occupy with reference to the position of the thermal equator rather than as characteristic of their position on the earth's surface, although the latter consideration enters to some extent. With this curve of figure 2 as a basis the chief seasonal, latitude, and other variations in the relation it represents, may be briefly stated. Diurnal variations of temperature which affect the slope of the curve in its lower part will not be considered here.[3]

In the middle latitudes marked seasonal variations occur in the lowest of the strata above defined. During the warm half of the year the temperature in this region falls somewhat irregularly with altitude, always at less than the adiabatic rate in the mean, but sometimes exceeding this rate for brief periods of time. In the winter months an inversion of temperature with the maximum temperature at about the 1-kilometer level is shown in the mean, although there are times when inverted temperature conditions do not obtain. In the second stratum above defined the slope of the curve remains about the same throughout the year, but the bounding planes of this stratum change position. The lower boundary is somewhat lower in the winter than in the summer months and the upper boundary is considerably lower, from 2 to 3 kilometers. In the third stratum the change from summer to winter consists chiefly in the decided lowering of the lower boundary just mentioned. The upper boundary of this stratum—i. e., the surface of minimum temperature—seems to rise slightly, when observations made in this country are considered. In the fourth stratum the rise of temperature with altitude seems to be not nearly so rapid in the winter as in the summer months. But 0.3°C. per kilometer is shown by the observations in the United States. The fifth stratum has not been observed in the winter months. In these middle latitudes the temperature in the surface of minimum temperature is some 2 or 3 degrees (C.) higher in the winter than in the summer months.

To some extent the seasonal variations may be thought of as variations with latitude, or in distance from the thermal equator. There is evidence that from the latitude of the thermal equator to about 40° north of it the surface of minimum temperature is found at lower levels and is warmer with increasing latitude, while from

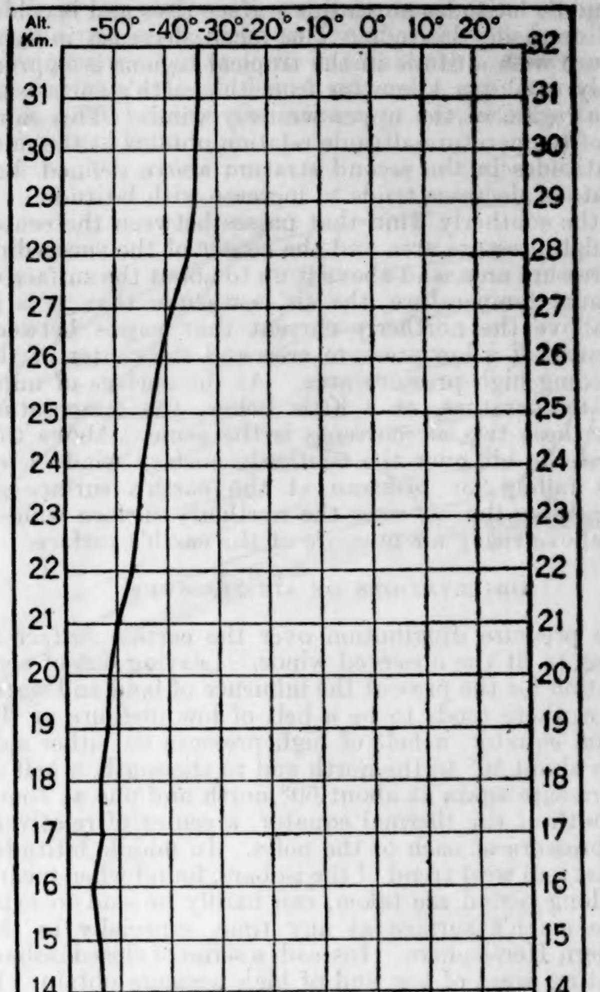


FIG. 2.—Mean of temperature-altitude relations observed in three high ascensions.

[2] According to the convention adopted by the International Commission for Scientific Aeronautics the temperature-altitude relation is positive when temperature decreases with altitude, negative when temperature increases with altitude.

[3] The diurnal system of convection has been treated in the Bulletin of the Mount Weather Observatory, Washington, 1913, v. 6, pt. 5.

the middle latitudes north this surface rises and is colder with increasing latitude. The mean decrease in temperature with altitude in the tropical regions is approximately 6° C. per kilometer from the earth's surface up to the region of the upper westerly winds. This same type of temperature-altitude relation obtains in the middle latitudes in the second stratum above defined, but the rate of decrease tends to increase with latitude.

In the southerly wind that passes between the center of a high pressure area and the center of the succeeding low pressure area, and above it up to about the surface of minimum temperature, the air is warmer than it is in and above the northerly current that passes between the center of a low pressure area and the center of the succeeding high pressure area. At the surface of minimum temperature, or a little below, the temperature above these two air currents is the same. Above this surface the air over the southerly surface wind—i. e., above falling air pressure at the earth's surface—is colder than the air over the northerly surface wind—i. e., above rising air pressure at the earth's surface.

OBSERVATIONS OF AIR PRESSURE.

The pressure distribution over the earth's surface is such as to fit the observed winds. Leaving out of consideration for the present the influence of land and water surface, there tends to be a belt of low pressure at the thermal equator, a belt of high pressure on either side of this about 30° to the north and to the south, a belt of low pressure again at about 60° north and one at about 60° south of the thermal equator, a center of relatively high pressure at each of the poles. In middle latitudes the east and west trend of the isobars, found when means for a long period are taken, can hardly be said to exist at the earth's surface at any time, especially in the Northern Hemisphere. Instead, a series of closed isobars indicating areas of low and of high pressure obtain. It is found, however, that these closed isobars begin to open up a short distance above the earth's surface. Those about a low pressure area open on the north side, as a rule, while those about a high pressure area open on the south side. The tendency seems to be for the isobars to open up to the left of and on a line at right angles to the direction of motion of the low, to the right of and on a line at right angles to the direction of motion of the high. Closed isobars above the 3-kilometer level seem to be of infrequent occurrence.

CONCERNING THE OBSERVATIONS IN GENERAL.

All of the above observations are closely related. The surface stratum in middle latitudes, in which the temperature-altitude relation is very variable, is the stratum of differently directed winds. The more permanent currents which have been explored up to and including the upper westerly wind seem everywhere to be accompanied by fairly characteristic temperature conditions. In them the temperature-altitude relation has a value between 5° and 7° C. per kilometer. The surface of minimum temperature is found near the upper boundary of the upper westerly wind. Observations indicate the approach to a surface of maximum temperature located in or above the upper easterly current. Based upon the observations that have been made, a statement to the effect that such a surface of maximum temperature exists can not be definitely made. The upper easterly wind has been, to a very limited extent only, explored by means of self-recording instruments. Above the heights reached by means of sounding balloons, the only means of free air observation have been furnished by the luminous meteor trains which often persist long enough after the passage of the meteor to enable an observer to determine their altitude and movement. As nearly as may be estimated from the few observations of this sort available the easterly wind may extend to about the 60-kilometer level. Above this the drift seems to be from a westerly direction again.

In figure 3 an attempt has been made to fit together all the above observations and to represent a meridional section of the planetary system of convection so far as it has been observed. The dashed line in this figure indicates the limits within which observations have been made.

GENERAL CONSIDERATIONS.

In considering this scheme of air movement and its relation to the pressure, temperature, and moisture distribution in the atmosphere there are a few more or less fundamental facts and laws that one needs to have in mind. These need only be stated since they are generally accepted.

1. The earth is the chief source of atmospheric heat, especially in the lower strata of the atmosphere. This heat is transferred from the earth to the air by conduction and by radiation. It is distributed in the atmosphere by convection and by radiation.

2. The absorption of solar radiation, while relatively inconsiderable in the lower strata of the atmosphere, may be a relatively important source of heat in the upper strata. In this connection it is of interest to note that in the lower latitudes some considerable part of the atmosphere is always in the earth's shadow. A rough calculation shows that at 524 kilometers above the poles the sun is always shining; that at 30 kilometers above the poles the sun shines seven months of the year instead of six as at the poles themselves.

3. The chief cause of convection is a sufficient amount of unequal heating of air masses so located that the colder air mass is at the same or higher levels than the warmer. It is also conceivable that air may change level from causes entirely mechanical, e. g., it would tend to be thrown outward from a rotating air mass and would be changing level if outward, or some component of outward, were upward.

4. Air is heated by radiation it absorbs. It is not heated by transmitted radiation. In other words, the heating of air by radiation is inversely proportional to its diathermance. The moisture of the air is the constituent that more than any other absorbs terrestrial and solar radiation, consequently a dry air mass is likely to be relatively cool and a moist air mass relatively warm, regardless of the relative height of these masses above the earth's surface. Further, air above a stratum of moist air receives less terrestrial radiation and air below it less solar radiation than air similarly located with reference to a stratum of dry air.

5. The amount of moisture that may be contained in any air mass is directly related to the air temperature. This fact is especially useful in thinking of moisture distribution in the lower atmosphere. According to Stoney's conception of the gravitational sorting of the constituent gases of the atmosphere, the constituent, water vapor, will, above a certain level, increase with altitude, relatively to the heavier constituents, nitrogen and oxygen. This law is especially important in thinking of moisture distribution in the upper atmosphere. To a certain ex-

tent it may be said that air temperature determines the moisture content of the lower atmosphere, while moisture content determines the air temperature of the upper atmosphere.

6. In both direction and rate, the flow of air on any "equigravic"[4] surface bears a definite relation to the lines in which this surface cuts isobaric surfaces. The direction of flow in the northern hemisphere tends to be along the isobars from left to right as one goes directly from high to low pressure, but opposite to this in the southern hemisphere. The rate of flow is inversely proportional to the distance between the isobars, or proportional to the pressure gradient.

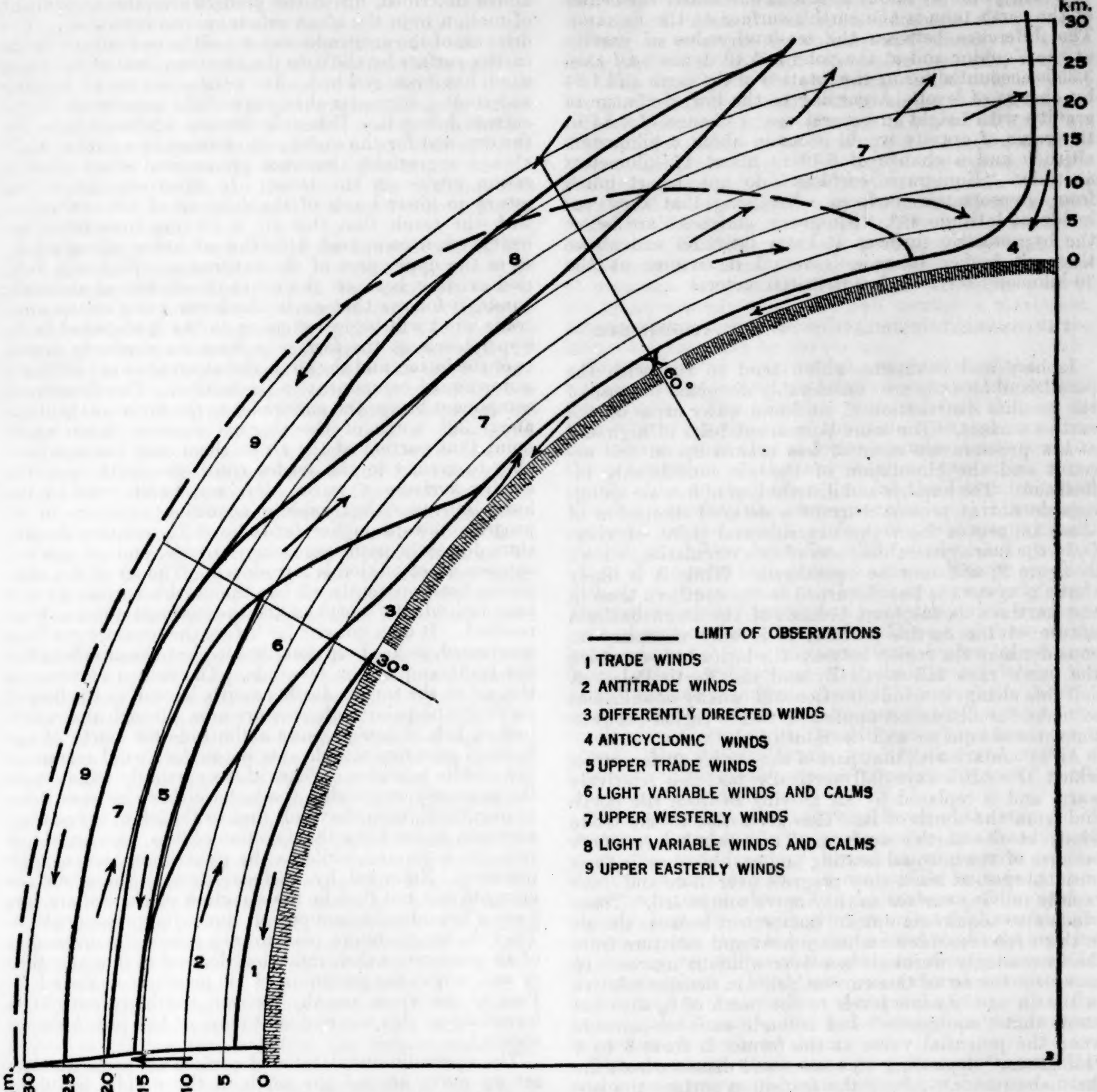


FIG. 3.—Meridional section of the planetary circulation up to the 30-kilometers level.

7. Barring change in its constitution, the potential temperature of an air mass tends to remain constant. Level, rate of flow, pressure, and temperature all vary in such ways as to take care of the topography and other characteristics of the bottom over which the air mass moves if it be moving, and to take care of warming or cooling by contact or by absorption and radiation,

[4] No entirely satisfactory name for the unit of gravity potential used in dynamic meteorology has yet been found. The value of this unit of potential is 10^5 ergs. The author suggests that the unit be called the "grav," pronounced as is the first syllable of gravity, that lines of equal gravity potential be called "equigravs," and that surfaces of equal gravity potential be called "equigravic surfaces." Since "g" is the abbreviation for the force of gravity and, in the C. G. S. system, for gram, it seems advisable to use "gv" as the abbreviation for "grav." This suggestion is put on trial above and following.—W. R. B.

whether it be moving or not. The "bottom" may be the earth's surface or it may be an aerial bottom. This is why a wind may become gusty. Since they are caused chiefly by the nature and topography of the bottom over which the current in which they occur flows, gusts are usually aperiodic.

8. The poles are about 22 kilometers nearer the center of the earth than is the earth's surface at the Equator. The difference between the sea-level value of gravity at the Equator and at the poles is 5.19 dynes. Of this, 3.35 is accounted for by the rotation of the earth and 1.84 by change of level. According to the law of change in gravity with height in general use, a change of 1.84 in the value of gravity would occur in about 6 kilometers altitude and a change of 5.19 in about 17 kilometers altitude. "Equigravic surfaces" do not depart much from hypsometric surfaces. Assuming that they coincide at latitude 45°, "equigravic surfaces" are below the hypsometric surfaces at lower latitudes and above them at higher latitudes. Actual departures at the 30-kilometer level are less than 100 meters.

THE GENERAL CIRCULATION OF THE ATMOSPHERE.

Isobars and isotherms which tend to run with the parallels of latitude are considerably distorted because of the peculiar distribution of land and water areas on the earth's surface. The more permanent belts of high and of low pressure are more or less broken up on this account and the circulation of the air considerably influenced. The number and distribution of free-air soundings do not at present warrant a detailed discussion of these influences from the experimental point of view. Only the more general features of this circulation, shown in figure 3, will now be considered. While it is likely that the system is less disturbed in the southern than in the northern hemisphere, because of the more uniform nature of the earth's surface, it is only necessary to consider here the region between the latitude upon which the sun's rays fall vertically and the North Pole. A suitable change in wind direction will usually be sufficient to make the discussion applicable to the region between the thermal equator and the South Pole.

Air in contact with that part of the earth's surface upon which the sun's rays fall vertically becomes relatively warm and is replaced by air moving in from the north and from the south of it. This gives rise to the trade winds at the earth's surface. These winds are north because of the unequal heating and east because, in their initial stages, at least, they progress over more and more rapidly moving surface as they move southward. These winds also acquire an upward component because the air in them receives more and more heat and moisture from the increasingly warm surface over which it moves. In its ascent the air of this current gains in density relative to the air at the same levels to the north of it, with the result that "equigravic" and isobaric surfaces coincide when the potential value at the former is from 3 to 6 "kilogravs," depending on season and distance from the thermal equator. Above the transition surface the isobaric surfaces cut the "equigravic" surfaces from below instead of from above as at lower levels, and the upward moving east wind acquires a component of motion from the south. As the southeast wind of these higher levels approaches higher latitudes it turns to the right, finally acquiring a component of motion from the west. The air of the trade winds in rising loses some of its moisture by precipitation. The air of the antitrade winds at higher altitudes is therefore differently constituted, having less moisture than the trades. This difference in constitution is of course small in the portions of these currents lying close together and more pronounced with distance from their common boundary plane. As a result of this change in constitution the transformation above described, up to the point where the component of motion from the south sets in, is not reversible. The drier air of the antitrades can not all have returned to the earth's surface by the time the northern limit of the trade wind has been reached. Its adiabatic rate of heating and cooling is greater than that of the moister air of the current below it. This difference in adiabatic rates for the dry and for the moist airs of these two strata, while always appreciable, becomes pronounced when condensation begins in the latter. It effectively limits the return to lower levels of the drier air of the antitrades, with the result that this air is for the time relatively heavy when compared with the air below it, especially so in the upper part of the antitrades. With this relation existing between the air in the trade and antitrade winds, it follows that air in the lower levels of the antitrade wind will begin returning to the trade wind in its upper levels as the former pursues its northerly course over the latter, and the air in the antitrade wind will have a downward component in its motion. This downward component brings the antitrades to the surface at latitude about 30° north of the thermal equator, from which point that portion of the air in them that has not been able to return to the trades continues north over the earth's surface—a warm, dry, southwest wind in the lower latitudes, but rapidly acquiring moisture in its progress toward higher latitudes.[5] Its relative density thus decreases with increasing latitude, and an upward component of motion is introduced. The air of the antitrades has apparently all left the earth's surface by the time latitude 60° north of the thermal equator has been reached. It does not rise far before the pressure gradient is reversed, as has been described in the transition between the trade and antitrade winds. The return of some of this air to the surface farther south, as well as the flow of air from the polar high pressure area through the rather broken belt of low pressure at latitude 60° north of the thermal equator, complicates the surface wind system of the middle latitudes. When these northerly winds meet the southerly antitrades, the latter either rise over them or pass them, with the result that to the left of the passing currents, as one faces the direction of flow, an area of low pressure is formed, while to the right is an area of high pressure. Retarded by surface friction, these surface currents can not flow in the direction of the isobars, but have a considerable component down the pressure slope. They do not therefore tend to mix across the maximum of air pressure on their right, but do tend to flow together or mix across the minimum of air pressure on their left. Part of the warm, usually moister, southerly current is forced up at this meeting, and more or less precipitation occurs.

The aperiodic undulations of surface air pressure thus set up move around the earth in the middle latitudes with about the speed and direction of the westerly wind at the 3-to-5-kilometers level. They have greater frequency and intensity in the winter months when the polar high pressure area is well developed than in the summer. The closed isobars about these maxima and

[5] The process by which the air of the trade winds passes (differently constituted in an important respect) into the air of the antitrade winds and the resulting lack of direct reversibility of the process has been described somewhat in detail because it is a typical process and one often found operating in the lower moist stratum of the atmosphere.

minima of surface air pressure begin to disappear a few hundred meters above the earth's surface, or with the decrease in the effect of friction between the earth's surface and the air. At 2 or 3 kilometers above the surface the isobars are no longer closed. Above these levels the trend of the isobars is along the parallels and the pressure slope is toward the north.

Tropical hurricanes probably have an origin somewhat similar to the less intense, larger low-pressure areas of the middle latitudes, except that in the Tropics the oppositely directed winds are in part at least of local origin. However it originates, the tropical hurricane, like the larger disturbances of the middle latitudes, moves with the air in the stratum just above the surface stratum in which it forms. In the case of the hurricane this upper current is the antitrade wind. In the case of the cyclones and anticyclones of middle latitudes the upper current is the upper westerly wind.

Above the antitrade winds of the lower latitudes the slope of the pressure gradient is again reversed. At these levels the air under which the antitrade winds descend in their northward journey is dense, relative to the air south of it, and an easterly wind with a component down the pressure slope is maintained. Because of the similarity in direction of these winds to the trade winds they have been called the upper trades. It is conceivable that in the northern part of the stratum occupied by these easterly winds the air will have a downward component. This component, together with heat it will receive from the earth's surface and from the air of lower levels, will affect the density of the air of the upper trades so that the downward component will disappear and, as it moves still farther south, an upward component will obtain. The upper trades are supplied with air by such return from the antitrades and air from the polar high pressure area as does not come down to the earth's surface and return to lower latitudes by way of the trade winds.

The downward component of air motion in the southern part of the stratum occupied by the antitrade wind and in the northern part of the stratum occupied by the upper trade wind has the effect of inclosing between these two strata, in the lower middle and upper tropical latitudes, a stratum of air in which there is no very well defined movement. This region of light winds and calms has been thought to accompany directly the high pressure observed at the earth's surface in the horse latitudes, but its area is more extensive than the high-pressure belt and besides the fairly steady antitrades pass under it, flowing under the influence of a pressure gradient sloping to the north, while above it the upper trades are moving under the influence of a pressure gradient sloping to the south. This transition stratum between the antitrades and upper trades has little or no depth in the lower tropical latitudes where the currents are both easterly, one with a small north and the other with a small south component. It is possible that some air from the upper trades may return to the antitrades before the former reach the thermal equator.

The increase in density of the air of the upper trades brought about by the upward component in its motion toward the thermal equator again gives rise to a reversal of the pressure gradient and a westerly current with a small south component obtains in the levels immediately above the stratum occupied by the upper trades. The upper westerly wind behaves in many respects like the antitrade wind and the somewhat detailed description of what happens to the air in its progress from the trade wind stratum into and through the antitrade stratum need not be repeated. The upper westerly wind differs from the antitrade wind in that the former does not at any time flow over the earth's surface. The air of the westerly wind is cold, dry, and, compared with the air at lower levels, relatively dense. It has a downward component of motion as it passes into higher latitude, as a result of which it undergoes adiabatic heating and appropriate changes in volume and density. In the lower latitudes air from the upper westerly wind is probably supplied to the upper trade wind over which it flows. The air that continues to higher latitudes forms a deeper current as it moves north in accord with the law that the area of its cross section times its density shall remain constant. This deepening of the current is not sufficient to keep its upper limit at the same level, at least until middle latitudes are reached. There is some evidence that the upper level rises from middle to higher latitudes. This being the case, there should be a position somewhere in the middle latitudes at which the surface of minimum temperature, located in the upper part of the upper westerly wind, will pass through a maximum, this maximum being coincident, or nearly so, with the lowest level reached by the surface.

In their journey northward the upper westerlies acquire some moisture from the air below them, especially in their lower levels. This, together with the fact that in the higher latitudes the air of the surface stratum contains less moisture than that at lower latitudes, tends to make the constitution of the airs in these two strata more nearly alike at the higher than at the lower latitudes. The direct result of this increasing similarity is the nearer approach to the earth's surface of the upper westerly wind in the higher latitudes. The shallow anticyclonic winds of the polar high-pressure area seem to be supplied with air on the poleward side by the upper westerly wind. The surface winds here tend to be easterly with a component of motion from the north. The air of these winds heats adiabatically as it moves from higher inland surfaces to sea level. Some of it thus heated leaves the earth's surface at latitude about 60° north of the thermal equator and some moves on to lower latitudes, where the result of its meeting with the antitrades has already been noted. The upper westerly wind is observed within a kilometer of the earth's surface at points 70° to 80° north and south latitudes.

The presence at relatively high levels of the stratum of dense air, found in the upper westerlies, has the effect of producing turbulence or turbulent convection in the stratum of air below it. In the middle latitudes turbulence occurs in the lower 2 to 5 kilometers of the atmosphere. Turbulence is likely to prevail at the lower boundary of any air mass occupying a level relatively high for its density, regardless of the position of such air mass in the atmosphere. Doubtless the antitrades contribute in this way to the intensity of tropical cyclones after the passing of differently directed currents in the stratum below has given rise to them.

The air under which the upper westerly current descends as it moves to higher latitudes will at some level above the latter become relatively dense when compared with the air south of it. A pressure gradient sloping to the south will be established in these upper levels and an easterly current with a component down the pressure slope maintained. The gradual deepening of the upper westerlies as they approach the poles, together with the diminution of the central force, g×cos. lat., has the effect of forcing air in the upper levels of the current to

great altitudes. As a result of its being forced up, this air becomes dense relative to the air south of it and augments to some extent the easterly current prevailing at these higher levels. Observations to sufficient height in these high latitudes are lacking, but it seems that the forces operating here must result in the return at higher levels of a small part, at least, of the air carried northward by the upper westerlies. As has been pointed out above, the tendency of the air in this current is downward, but its high rate of adiabatic heating in descent, when compared with adiabatic rates of heating and cooling in the air below it, limits its return southward on its underside until extremely high latitudes are reached. Here the other forces mentioned tend to some extent to operate against the return at lower levels.

A stratum of comparatively quiet air, similar to that inclosed between the anti and upper trades, only of much greater extent, will be inclosed between the upper limit of the upper westerlies and the lower limit of the upper easterlies. The vertical extent of this stratum decreases toward its southern limits. As observed in the Tropics, the upper easterly wind passes immediately over the upper westerly wind. At this point of contact, probably in the lower middle or upper tropical latitudes, a return of air from the upper to the lower of these two currents takes place, sufficient to balance the interchange of air between them over the polar regions.

It should be noted that the supply of air from the upper westerly to the upper easterly wind in the polar regions, while it may take the form of a deep current there, will be a very shallow layer of air when distributed over the larger area covered by the easterly current as it goes south. The depth of the upper easterlies observed in the tropical regions, 6½ kilometers, indicates a very deep current in higher latitudes.

It appears from the above considerations that air over the thermal equator is, on the whole, rising at all levels so far explored and descending at higher latitudes. The rate of vertical motion must be exceedingly slow, since the upward or downward components of motion are required to carry the air only a few kilometers in the same time that the horizontal components carry it thousands of kilometers. The ratio of the vertical to the horizontal components of motion in the lower strata is less than in the higher. The latter currents travel more uniformly and to much greater distances than the former.

The general north and south movement of the whole system of winds above described may be caused by an aperiodic variation in the amount of solar energy reaching the earth's surface in the tropical low-pressure belt. The formation of a cloud cover in this region results from active heating of the earth's surface. This cloud cover reflects more than half the solar radiation incident upon it, with the result that the cover may, partially at least, disappear, allowing the earth's surface to be heated again, and so on. Such a variation would have the effect of varying the amount of solar energy used in the tropical low-pressure belt and of varying the width and position of the belt itself, thus increasing and decreasing the north-south component of the whole circulatory system.

Whatever its cause, this general north and south movement of the atmosphere up to the highest levels explored is peculiar in that the change in rate of meridional motion from the time of its greatest northward to the time of its greatest southward speed is rather gradual, this period being from 4 to 10 days. The change from greatest southward to greatest northward motion occupies a comparatively short time.

Some years ago Mr. E. H. Bowie called the writer's attention to the fact that the low-pressure areas enter and cross the United States in series. The first low-pressure area in such a series will enter the country well to the north and pursue a course eastward over the northern States, the second enters somewhat farther south, and so on. The last low-pressure area of the series may enter the extreme Southwest and pass along the Gulf and Atlantic coasts, although the series do not always carry as far south as this. The series follow each other in close succession. The relation between these series of low-pressure areas and the general meridional movement of the atmosphere seems to be quite direct. The fact that the low-pressure areas of any series pursue more nearly the same path across the North Atlantic than they have pursued across the continent seems to indicate that the change in position of the thermal equator occurs mostly over land areas. It is possible that the meridional motion found over the continental area is compensated by a meridional motion in the opposite direction of the oceans.

TEMPERATURE AND PRESSURE DISTRIBUTION.

The general features of the temperature and pressure distribution, especially in so far as they give rise to the circulatory system just described, have already been considered. It is the intention of this part of the paper to consider peculiarities in the distribution of these elements that have been observed in certain regions of the atmosphere.

The surface of minimum temperature near the upper limit of the upper westerly current has been of great interest to meteorologists since its discovery about 20 years ago. Many observations of it by means of sounding balloons have been made, but unfortunately these observations are not so well distributed as could be desired. The great majority of them have been in middle and upper middle latitudes. A remarkable feature of this surface of minimum temperature, as observed in the middle latitudes, is the large variation in its temperature from day to day. Based largely upon these observations of temperature variation, variations in air pressure have been found to exist. All of these changes in the region of minimum temperature are found closely related to the changes in the same elements observed at and near the earth's surface, as low and high pressure areas pass.

This relation is so close that some have gone so far as to look to the stratum of minimum temperature for the cause of the low and high pressure areas.[6] It is conceivable that gustiness of the upper westerly wind could cause variations in the air pressure at the earth's surface similar to those observed, but if this be the order of cause and effect the succession of high and low pressure areas would not be confined to the middle latitudes, since the upper westerly wind is observed at all latitudes. Moreover, it would be difficult to assign a cause for such gustiness in the upper westerly current. In the writer's opinion the high and low pressure areas are brought about by the passing of differently directed currents as described above, and the rough aerial bottom, owing to this cause, over which the upper westerlies must pass in the middle latitudes, accounts for their gustiness. Some contribution to the intensity of the disturbances thus

[6] *Shaw, W. N.* Principia Atmospherica: A study of the circulation of the atmosphere. Proc., Roy. Soc. of Edinburgh, v. 34, pt. 1, no. 9. *Reprinted* in this REVIEW, April, 1914; there particularly see p. 203.

caused in the lower stratum may be directly attributed to the overlying of the relatively dense stratum of air. This effect will be similar to that produced by the air of the antitrades, in the case of tropical cyclones, but it will be less pronounced in the case of these large area disturbances. If this be the correct interpretation of the phenomena observed in the middle latitudes, observations in higher and lower latitudes where surface winds are steadier than in the belt traversed by the areas of high and low pressure should show less gustiness, or none at all, in the upper westerly current.

It is only because the upper westerlies rest heavily on the bottom over which they flow that they find it necessary thus to adapt themselves to all its irregularities. The air in them is, as has been pointed out above, relatively dense for the level it occupies because of its dryness when compared with the air below it. It is for this reason that this gustiness does not occur in levels above the upper westerlies. It has been pointed out by those who seek the cause of the surface areas of high and of low pressure in the coldest part of the upper westerly current that the amplitude of the temperature and pressure variations here are even greater than at any level below. This is to be expected, because the temperature changes accompanying a given expansion or contraction of dry air are decidedly greater than those accompanying the same expansion or contraction of moist air, and, since values of the pressure-altitude relation are deduced largely from consideration of the temperature variation and not independently, the variations of pressure in these levels appear greater than they really are when compared with the variations of pressure at lower levels.

This interaction between the airs belonging to the surface and to the upper westerly winds doubtless plays an important part in the determination of the forward movement of the high or low pressure area over the earth's surface. These areas, it has been noted, seem to have the speed and direction of the air movement at the 3 to 5-kilometers level. The same may be said about the interaction between the airs of the trades and antitrades in the case of tropical cyclones. These cyclones, while in the tropical belt, seem to travel with the speed and direction of the antitrades.

Some work by the writer on the gustiness of surface winds is in progress, and an illustration of this may be of interest here. Figure 4 illustrates the changes of speed and direction of air movement and of pressure during the hour 8 to 9 a. m., February 4, 1916, as recorded at the Weather Bureau Observatory, Washington, D. C. The wind gusts during this hour are selected because of their regularity and of the low velocity of the wind in which they occur. Their regularity enables one to follow the changes more easily. By selecting a wind of low velocity, errors, owing to the inside exposure of the barometer, may be neglected in comparison with the effects being observed. Unfortunately, the only record of temperature available is of small scale, and the beginning and ending of the hour can not be closely located except by inference from the other records. The records by the wind vane, pressure-tube anemometer, and compensated mercurial barograph are all large scale and capable of fairly accurate reproduction.

It has been pointed out above that the air of the upper westerly wind is dry and dense when compared with the air below it, especially in the lower latitudes. The same may be said of the air in this current when compared with the air above it. Now, while this air mass holds a position somewhat higher in the air because of its dryness than its density entitles it to, it does not much affect the passing in of solar radiation and the passing out of terrestrial radiation. It has also been pointed out that the air of the upper westerly wind becomes more and more like the airs above and below it as it journeys northward. The only effect of this relationship between the air of the upper westerly current and the airs of the strata immediately above and below it is a rather decided minimum in the value of the temperature-altitude relation in the lower latitudes, this minimum being less pronounced with increasing latitude. It follows that above the surface of minimum temperature, found in the upper westerly current, the air temperature increases with altitude. This increase is

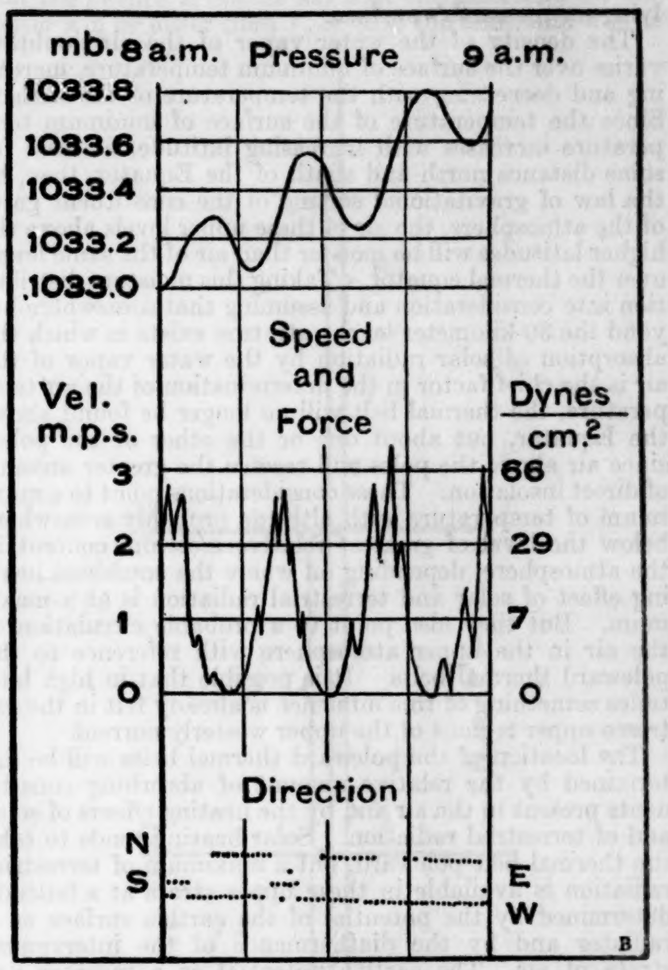


Fig. 4.—Relation between speed, force, pressure, and direction in wind gusts.

more rapid in the lower latitudes than in the higher and more rapid in the summer than in the winter months, so far as observations go. That terrestrial radiation is still effective at these high altitudes is shown by the difference in temperature here, owing to the difference in the screening effects of relatively dry and moist masses of air at levels below the surface of minimum temperature. Observations confirm the conclusion that the upper westerly wind is dry, when compared with air at lower levels. That the air of this current is dry, relative to the air above it, is also a matter of observation. It may be argued that, since the H_2O molecule is considerably lighter than that of nitrogen or of oxygen, the decrease in all three constituents with altitude will result in an

increasing proportion of water vapor in the air with altitude up to a certain height. This limiting height can not be definitely determined, because air temperatures in these very high levels are not known. It is probable that it occurs below the 100-kilometer level. Observations indicate that of the total solar energy absorbed by the air from two-thirds to three-fourths is absorbed by the water vapor of the air. In view of the probability that at no great height above the surface of minimum temperature the moisture content of the air is a greater percentage of the whole air mass than at any lower level, solar heating of the air in these upper levels is likely to become relatively important. Especially is this true when we consider that at these levels there is available for absorption something over twice the amount of solar radiation available in the stratum of air lying on the earth's surface.

The density of the water vapor of the air doubtless varies over the surface of minimum temperature, increasing and decreasing with the temperature of the surface. Since the temperature of the surface of minimum temperature increases with increasing latitude, at least for some distance north and south of the Equator, then, by the law of gravitational sorting of the constituent gases of the atmosphere, the air of these upper levels above the higher latitudes will be moister than air of the same levels over the thermal equator. Taking this moisture distribution into consideration and assuming that somewhere beyond the 30-kilometer level a stratum exists in which the absorption of solar radiation by the water vapor of the air is the chief factor in the determination of the air temperature, the thermal belt will no longer be found above the Equator, but about one or the other of the poles, since air above the poles will receive the greater amount of direct insolation. These considerations point to a maximum of temperature with altitude probably somewhere below the level of greatest relative moisture content in the atmosphere, depending on where the combined heating effect of solar and terrestrial radiation is at a maximum. But they also point to a probable circulation of the air in the upper atmosphere with reference to the poleward thermal belts. It is possible that in high latitudes something of this influence is already felt in the extreme upper regions of the upper westerly current.

The location of the poleward thermal belts will be determined by the relative amount of absorbing constituents present in the air and by the heating effects of solar and of terrestrial radiation. Solar heating tends to take the thermal belt poleward, but a maximum of terrestrial radiation is available in these upper strata at a latitude determined by the potential of the earth's surface as a radiator and by the diathermance of the intervening strata of air. The earth's potential as a radiator decreases with latitude, while the diathermance of the intervening air increases with latitude. It is probable, therefore, that the influence of terrestrial radiation on the position of the poleward thermal belts will be to keep them away from the poles, especially in their lower levels. The belts should approach the poles with increasing altitude. Observations for determining, qualitatively at least, the relative importance of solar and terrestrial heating of the air at different levels are in progress, but considerable time will be needed for their completion. At best they will be limited as to latitude.

It should be stated that, on the assumption of a uniform horizontal distribution of absorbing constituents in these very high levels and entirely independent of the relative importance of solar and terrestrial radiation as sources of heat, relatively warm belts would exist around the poles at a latitude determined by the diathermance of the lower strata of air and the earth's potential as a radiator. These belts would owe their existence to the relatively greater amount of terrestrial radiation available for absorption at their latitudes than at any other latitude. For the same reason a minimum of temperature, or a relatively cold belt, would be found over the thermal equator where the screening effect of the lower strata of air is greatest. This reversal in the positions of the hot and cold belts, in the very high levels referred to, would be analogous to the reversal, in point of time, of the positions of the diurnal maximum and minimum of temperature which is found above the 1.5-kilometer level and would have a similar cause. As pointed out, the distribution of absorbing constituents and the possible relative importance of solar heating of the air in these high levels tend to strengthen the horizontal temperature gradients which must exist, as well as the circulation accompanying them.

The consideration of this subject indicates the necessity for a better distribution of the high level observations before final conclusions can be drawn. It also points out the great value of observations of air movement at all levels. There is need of a system of observations extending as far to the north and to the south as possible along one or more meridians.

SUMMARY.

1. This paper makes no attempt directly to show that the distribution of temperature in the atmosphere is in keeping with the fact that, in the long run, incoming and outgoing radiation balance each other. Recognizing this law, it attempts to show how the general circulation of the atmosphere is maintained and the influence of this circulatory system on the distribution of temperature and pressure in any particular part of the atmosphere.

2. Many of the atmospheric phenomena peculiar to given locations and seasons are not altogether of local origin, but are related more or less directly to the planetary system of convection. Among these phenomena may be mentioned: (1) The more decided minimum in the value of the temperature-altitude relation over middle latitudes in the summer than in the winter; (2) the variations in the temperature and the position of the surface of minimum temperature with latitude and, in the middle latitudes, with the passing over the earth's surface of high and low pressure areas; (3) the cyclonic and anticyclonic disturbances of the middle latitudes and to some extent the tropical cyclones.

3. The chief cause of nonreversibility of adiabatic transformations in the free air seems to be the change of constitution which takes place in the air during the transformation. The absorption and radiation of heat by the air mass under consideration enters to a greater or less extent, depending on the time occupied by the transformation and the amount of air in the mass, but this relation between the time and amount of air concerned in the transformation is usually such that the effect of absorption and radiation by the air is small.

4. The temperature conditions above the surface of minimum temperature are considered and some tentative conclusions, based on the distribution of atmospheric constituents, and on the relative heating effects at these high levels of solar and of terrestrial radiation, are drawn.

5. While turbulence or turbulent convection is found to be more active in some regions of the atmosphere than in others, convective circulation of the atmosphere obtains throughout the explored regions and doubtless for many kilometers above.

SECTION II.—GENERAL METEOROLOGY.

THE AVERAGE INTERVAL CURVE AND ITS APPLICATION TO METEOROLOGICAL PHENOMENA.[1]

By W. J. SPILLMAN, H. R. TOLLEY, and W. G. REED.

[Dated: U. S. Office of Farm Management, Washington, Apr. 13, 1916.]

In cooperation with the Bureau of Plant Industry the Office of Farm Management recently undertook a study of methods and cost of heating greenhouses. In these investigations detailed studies were made of the heating systems in a large number of commercial establishments. In prosecuting this investigation in central and southern latitudes we met everywhere the question on the part of the growers: "What is the lowest temperature we are liable to have once in 30 years?" These men were of opinion that it would be cheaper to stand a loss once on 30 years than to go to the expense of providing against it.

Temperature is, of course, not the only factor in the problem. Wind velocity is quite as important. It is the combination of low temperature and high wind that sends the cold chills down the back of the man who has extensive investments in greenhouses.

It may be of interest to note that we did not meet the above query when these investigations were extended into the northern districts. Greenhouse men there informed us that when the temperature falls below about 20° F. the moisture in the house freezes on the glass and seals up the chinks, so that it actually costs less to heat a hothouse full of growing plants with outside temperatures below 20° than with temperatures slightly above this point.

It is not difficult when the mean and the standard deviation of the extreme winter minima are known for a given locality, to calculate the average frequency with which temperatures lower than any assigned limit will occur or the temperature limit that will be exceeded once on the average in a given number of years. However, the labor involved is considerable, especially when the calculations must be made for several stations, and more especially when several temperatures or intervals are concerned. In making these calculations for a large number of stations it occurred to the senior author of this paper to shorten the labor by constructing a curve with average intervals between successive occurrences of a minimum lower than a given temperature, T, as ordinates and with the departure of T from the mean as abscissæ, T being expressed in terms of the standard deviation as the unit. Accordingly he constructed such a curve (see fig. 1). The equation of this curve was derived from the following considerations: In the theory of probability, unity represents certainty. An even chance is represented by the fraction $\frac{1}{2}$. Assuming that the frequency curve for the extreme winter minima is normal, which it is nearly, it is an even chance whether the lowest temperature during any one winter will be above or below its average value for any particular locality. The probability that it will be below the mean is therefore $\frac{1}{2}$, as indicated in figure 2. Let P represent the probability that it will lie between the mean, M, and some temperature, T, lower than the mean. Then the probability that it will lie below T is $\frac{1}{2}-P$. Suppose that in a given case the value of this latter probability is 1/10. This means that the chance is one in ten that the minimum for the winter will be lower than T, or that the minimum will be lower than T on the average once in ten years. Thus, the probability is 1/10, and the average interval is 10. The average interval between the occurrence of minima below T is thus the reciprocal of the probability of such occurrence, a general principle, applicable to all cases. If, then, the average interval be represented by A, we have $A=1/(\frac{1}{2}-P)$. The value of P can be expressed in terms of the standard deviation and the departure of T from the

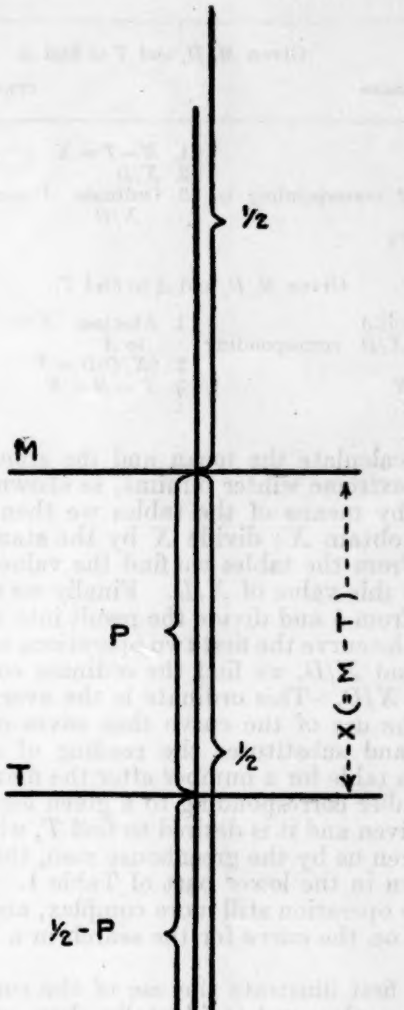


FIG. 2.—Diagram illustrating the probability, P, that the lowest temperature of any one winter will lie between the mean minimum temperature, M, and some temperature, T; lower than M; below T; and above M.

[1] A paper read before the Philosophical Society of Washington, Apr. 1, 1916.

mean, which departure is usually represented by X. Substituting this value for P in the last equation we have

$$A=\frac{1}{\frac{1}{2}-\frac{1}{\sqrt{2\pi}}\left(\frac{X}{D}-\frac{1}{3\times2}\frac{X^3}{D^3}+\frac{1}{|\underline{2}\times5\times4}\frac{X^5}{D^5}-\frac{1}{|\underline{3}\times7\times8}\frac{X^7}{D^7}+\&c.\right)}.$$

The above equation is the equation of the average interval curve, the values of A constituting the ordinates and those of X/D the abscissæ.

Table 1 has been constructed to give a comparison of the use of this curve as compared with the use of the ordinary probability integral tables in problems of the kind here under consideration. Suppose the problem is to find the average interval between successive occurrences of an absolute winter minimum lower than T.

TABLE 1.—*Comparison of use of tables and the curve.*

Given M, D, and T to find A.

TABLES	CURVE
1. $M-T=X$ 2. X/D 3. Value of P corresponding to X/D 4. $A=1/(\frac{1}{2}-P)$	1. $M-T=X$ 2. X/D 3. Ordinate A corresponding to X/D

Given M, D, and A to find T.

TABLES	CURVE
1. $P=(A-2)/2A$ 2. Value of X/D corresponding to P 3. $(X/D)D=X$ 4. $T=M-X$	1. Abscissa X/D corresponding to A 2. $(X/D)D=X$ 3. $T=M-X$

We first calculate the mean and the standard departure of the extreme winter minima, as shown in figure 1. To find A by means of the tables we then subtract T from M to obtain X; divide X by the standard deviation; then from the tables we find the value of P corresponding to this value of X/D. Finally we subtract the value of P from $\frac{1}{2}$ and divide the result into unity.

In using the curve the first two operations are the same. Having found X/D, we find the ordinate corresponding to abscissa X/D. This ordinate is the average interval sought. The use of the curve thus saves one complex operation, and substitutes the reading of a curve for hunting in a table for a number after the manner of finding the number corresponding to a given logarithm.

If A be given and it is desired to find T, which was the problem given us by the greenhouse men, the operations are as shown in the lower part of Table 1. Here again we save one operation still more complex, and substitute the reading on the curve for the search in a table of figures.

We shall first illustrate the use of the curve in some concrete examples, and incidentally show something of the applicability of the method to meteorological prediction.

The first column of Table 2 gives the absolute winter minimum at Philadelphia for 24 successive winters. This number of values of the variable is too small for any great degree of accuracy, but will serve for purposes of illustration. We first calculate the mean and the standard deviation in the usual way (see fig. 1). It will be noticed that 13 of the minima of Table 2, or one more than half, are below the mean, which is 5.04°F. This gives some idea of the closeness of fit of the normal frequency curve in this case, since theoretically half of them should be above and half below the mean.

TABLE 2.—*Absolute winter minimum temperatures at Philadelphia, and calculation of the mean and the standard deviation.*

Minima.	X'.	$(X')^2$.	Calculation.
°F.			
19	14	196	
4	1	1	
10	5	25	
−5	10	100	
4	1	1	
8	3	9	$M=121/24=5.04$.
12	7	49	
3	2	4	$M'=5$.
−5	10	100	
−1	6	36	$n=24$.
6	1	1	
9	4	16	
10	5	25	
5	0	0	$D=\sqrt{\frac{S(X'^2)}{n}-\frac{r^2}{n^2}}=5.877$.*
−2	7	49	
7	2	4	
2	3	9	(For meaning of symbols see explanations in fig. 1, facing p. 198.)
2	3	9	
9	4	16	
13	8	64	
10	5	25	
0	5	25	
4	1	1	
−3	8	64	
Totals... 121	....	829	

* This modification of the common formula for computing the standard deviation, is due to Prof. C. F. Marvin, Chief of the Weather Bureau, who has kindly consented to its use here in advance of publication. The new formula is much more convenient for computation than the one commonly used.—*W. J. S.*

Let us now find the temperature below which the winter minimum should be expected to fall once on the average in 30 years. The abscissa corresponding to ordinate 30 on the curve (fig. 1) is 1.834. This, then, is the value of X/D. Multiplying by 5.877, the previously found value of D, we find $X=10.778$, which gives for T the value of -5.738 degrees (F.). Theoretically, the lowest winter temperature at Philadelphia should thus fall below $-5.738°$ once on the average in 30 years. Reference to Table 2 shows that during the 24-year period of observation there recorded the temperature did not quite reach this low level, but did reach $-5°$ on two occasions.

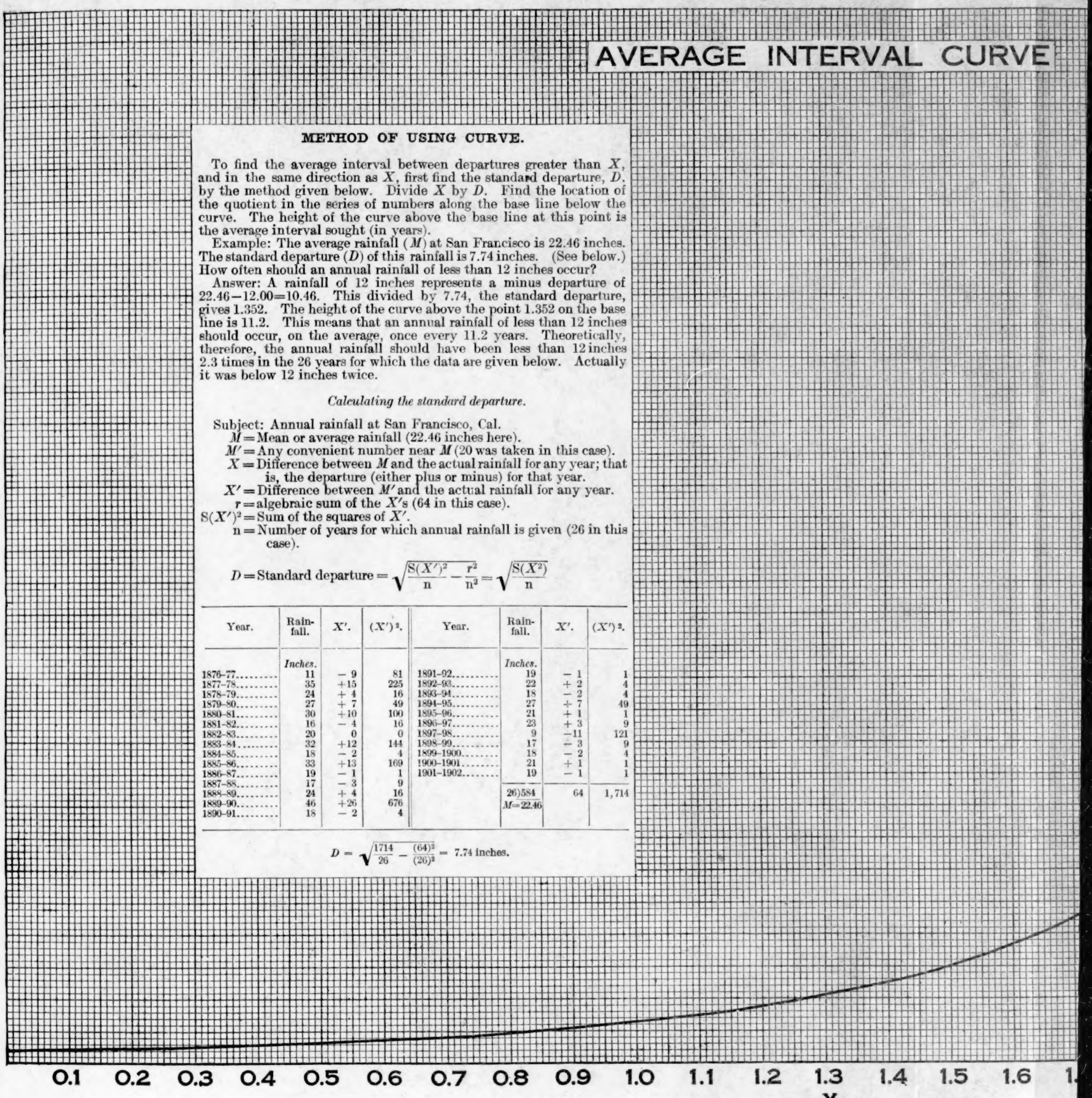
To further test the reliability of this method of prediction let us determine how often the temperature should fall below zero. In this case $X=5$, and $X/D=0.85$. On the curve this abscissa corresponds to $A=5$; hence the temperature should fall below 0°F. once on the average in five years. During the 24 years for which data are available it did fall below five times, which agrees with the calculated value of A.

There are three important limitations in the application of the method here outlined to meteorological phenomena. The first lies in the fact that the periods for which data are available give so few values of the variable that the resulting values of the mean and the standard deviation are not as reliable as it is desirable they should be. Nevertheless, when the frequency curve is approximately normal, the results calculated from 20 years' observations are fairly satisfactory, as will be seen below.

The two junior authors of this paper have calculated the standard deviation of the date of last killing frost in spring for 569 stations, the data for which were kindly furnished by the Weather Bureau. The length of the record at these stations covers 10 to 59 years, as shown in Table 3.

TABLE 3.—*Records used as a test of the reliability of the method.*

Length of record (years).	Number of stations.
10-16	6
17-19	43
20-23	338
24-29	115
30-39	43
40-46	23
59	1
Total	569



METHOD OF USING CURVE.

To find the average interval between departures greater than X, and in the same direction as X, first find the standard departure, D, by the method given below. Divide X by D. Find the location of the quotient in the series of numbers along the base line below the curve. The height of the curve above the base line at this point is the average interval sought (in years).

Example: The average rainfall (M) at San Francisco is 22.46 inches. The standard departure (D) of this rainfall is 7.74 inches. (See below.) How often should an annual rainfall of less than 12 inches occur?

Answer: A rainfall of 12 inches represents a minus departure of 22.46−12.00=10.46. This divided by 7.74, the standard departure, gives 1.352. The height of the curve above the point 1.352 on the base line is 11.2. This means that an annual rainfall of less than 12 inches should occur, on the average, once every 11.2 years. Theoretically, therefore, the annual rainfall should have been less than 12 inches 2.3 times in the 26 years for which the data are given below. Actually it was below 12 inches twice.

Calculating the standard departure.

Subject: Annual rainfall at San Francisco, Cal.

M = Mean or average rainfall (22.46 inches here).

M' = Any convenient number near M (20 was taken in this case).

X = Difference between M and the actual rainfall for any year; that is, the departure (either plus or minus) for that year.

X' = Difference between M' and the actual rainfall for any year.

r = algebraic sum of the X's (64 in this case).

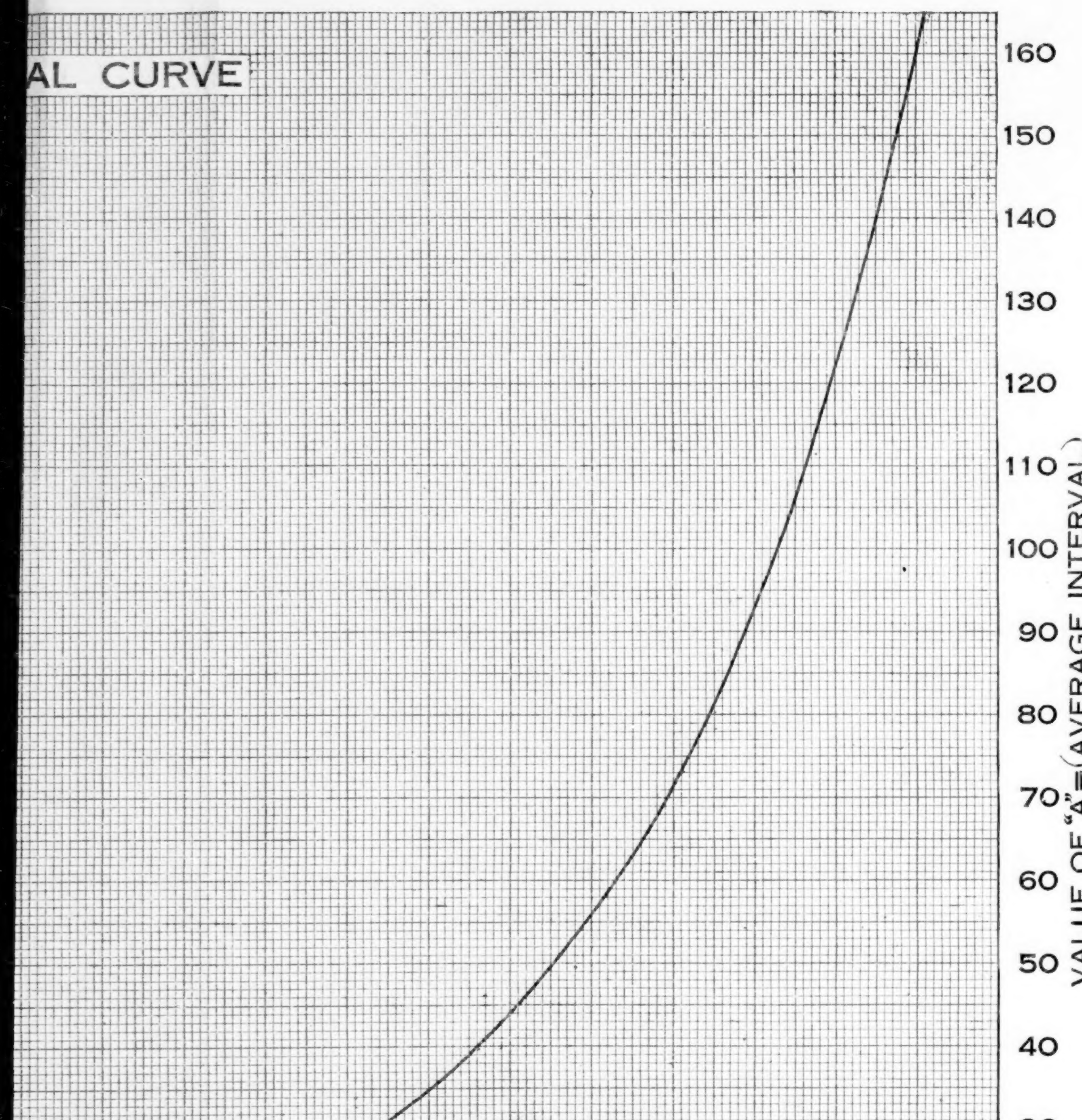
$S(X')^2$ = Sum of the squares of X'.

n = Number of years for which annual rainfall is given (26 in this case).

$$D = \text{Standard departure} = \sqrt{\frac{S(X')^2}{n} - \frac{r^2}{n^2}} = \sqrt{\frac{S(X^2)}{n}}$$

Year.	Rainfall.	X'.	$(X')^2$.	Year.	Rainfall.	X'.	$(X')^2$.
	Inches.				*Inches.*		
1876-77	11	−9	81	1891-92	19	−1	1
1877-78	35	+15	225	1892-93	22	+2	4
1878-79	24	+4	16	1893-94	18	−2	4
1879-80	27	+7	49	1894-95	27	+7	49
1880-81	30	+10	100	1895-96	21	+1	1
1881-82	16	−4	16	1896-97	23	+3	9
1882-83	20	0	0	1897-98	9	−11	121
1883-84	32	+12	144	1898-99	17	−3	9
1884-85	18	−2	4	1899-1900	18	−2	4
1885-86	33	+13	169	1900-1901	21	+1	1
1886-87	19	−1	1	1901-1902	19	−1	1
1887-88	17	−3	9				
1888-89	24	+4	16		26)584	64	1,714
1889-90	46	+26	676		M=22.46		
1890-91	18	−2	4				

$$D = \sqrt{\frac{1714}{26} - \frac{(64)^2}{(26)^2}} = 7.74 \text{ inches.}$$



AL CURVE
VALUE OF "A"=(AVERAGE INTERVAL)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5

Mr. Tolley and Mr. Reed have also calculated, by means of the average interval curve, the theoretical date after which frost should occur once in 10 years at each of these stations, and made a comparison between the theoretical number of frosts after this date, which is 1 for each 10 years, and the actual number at each of the 569 stations. Table 4 shows the results. At 414 stations there were no unexpected frosts. This is 72.75 per cent of the entire number of stations. There was 1 unexpected frost at 123 stations, 2 at 29 stations, and more than 2 at 3 stations. Thus in 94.35 per cent of the cases there was not more than 1 unexpected frost during the period of observation, which in most cases was 20 to 29 years.

TABLE 4.—*Number of stations having specified numbers of unexpected frosts.*

Stations having unexpected frosts.	Number of stations.	Per cent.	Cumulative per cent.
None	414	72.75	72.75
One frost	123	21.60	94.35
Two frosts	29	5.10	99.45
Three or more	3	0.55	100.00
Sums	569	100.00	....

In some types of farming, especially in the production of early vegetables, the ability to reach the market before the main supply arrives means greatly enhanced profits to the farmer. He is therefore justified in taking some risk from having his vegetables killed by frost in order that he may in those years when he is lucky enough to escape frost obtain the high prices which prevail early in the season. He therefore takes chances. The question is whether it is better for him to go it blindly, with only the vaguest impressions to guide him as to the risk he is taking, or to rely upon a theoretical risk, which in 73 per cent of the cases leads to no unexpected losses and in 94 per cent to not more than 1 such loss in a period of 20 to 30 years.

As the periods of observation at the various meteorological stations lengthen, the value of the mean and of the standard deviation for each of these stations can be determined with increasing precision, so that the calculated average intervals between frost after any assigned date will become more and more reliable.

The second limitation of the method here presented lies in the fact that the frequency distribution of many meteorological phenomena can not be accurately represented by a normal frequency curve. The investigations of Mr. Tolley and Mr. Reed have shown that in the case of last frost in spring and first frost in fall the normal frequency curve fits the facts very satisfactorily, but in the case of rainfall the fit is not so satisfactory. We have calculated Pearson's skew curves for rainfall data, but we find that the results for the small number of values of the variable available in any case are very unsatisfactory, the normal frequency curve giving a better fit than Pearson's skew curves.

We have also constructed the frequency polygon for the occurrence of droughts covering different periods. The corresponding frequency curve is what is known to mathematicians as a J-shaped curve, and the method here outlined is not applicable to such a variable.

The method of using the average interval curve outlined in figure 1 makes use of rainfall as an illustration. The average rainfall at San Francisco for the period 1876–7 to 1901–2 is 22.46 inches and the standard deviation 7.74 inches. Under these conditions, how often should the rainfall be less than 12 inches?

Twelve inches represents a departure of 10.46 inches. This divided by the standard deviation, 7.74 inches, gives abscissa 1.352, which on the average interval curve corresponds to about 11.2 years. The theoretical frequency of rainfalls less than 12 inches for the 26-year period of observation is thus 26/11.2, or 2.32. The table in the figure shows that it actually fell below this value twice in this period.

How often should the rainfall at San Francisco fall below 18 inches? Here we have a departure of 4.46 inches, which divided by the standard deviation gives 0.576 for the abscissa, which corresponds to ordinate 3.6; that is, to an average interval of 3.6 years. In 26 years, therefore, the annual rainfall should fall below 18 inches 7.22 times. If we count the 4 years in which the rainfall is recorded as 18 inches as being half below and half above 18, we have the rainfall below 18 inches 6 times in the 26 years, instead of the theoretical 7.22 times.

This gives some idea of the general agreement between the calculated and the actual departures of rainfall. These values for the frequency of low rainfall are of importance in the selection of farm lands, especially in regions where the rainfall is light. A farmer who knows that the average rainfall in a given locality is 15 inches and that on the average he must be content with a rainfall as low as 8 inches once, say, in five years, is less likely to pay exorbitant prices for dry lands than the one who knows nothing about such things.

The third limitation of the usefulness of the information to be obtained by the method herein outlined lies in the fact that when a given event occurs once on the average, say, in 10 years, this does not mean that it will occur at regular intervals of 10 years. It does mean that in a century it will occur about 10 times; but these 10 occurrences will be scattered more or less at random throughout the century. When the average interval between such occurrences is 10 years the probability that it will occur in any year is one-tenth. But it may occur in two successive years, though the likelihood of this is so remote that it should not occur *on the average* more than once or twice in a century. If the average interval should be five years, then the event should not occur in two successive years oftener than about once in a quarter of a century.

The matter is somewhat further complicated by the occurrence of more or less distinct cycles in meteorological phenomena. But so little is known of these that they can not be taken into consideration in an article of this character.

Localities frost free in some years.

The method of calculating the average interval between frosts after a given date may be extended to localities in which frost does not occur every year, though it is necessary to have longer records in such cases to make the results of value.

Let L represent the number of years for which records are available, R the number of years in which frost occurred during the period L, A the average interval (in years) between last frosts after date C if frost occurred every year, and $1/Y$ the actual probability of frost after date C. In this case $1/A$ would be the probability of frost after date C, if frost occurred every year.

Case I. When the probability of frost after date C is less than half the total probability of frost; that is, when $1/Y$ is less than half of R/Y. The value of A in this case is found from the proportion

$$1/Y : 1/A :: R : L,$$

from which $A = RY/L$. Since R and L are known, either A or Y can be found when the other is known, and one of them is always known in problems of the kind here under consideration.

Case II. When the probability of frost after date C is just half the total probability of frost; that is, when $1/Y = R/2L$. Substituting this value of $1/Y$ in the proportion of Case I, and reducing, we have $A = 2$. In this case the date C coincides with the average date of last frost.

Case III. When the probability of frost after date C is greater than half of R/L and less than R/L. In this case the value of A is less than 2, and is hence not on the curve; but if we deal with the probability of last frost occurring before date C, instead of after C, we shall then find a value of A that does lie on the curve. The date C will then come before the mean date of last frost.

Since the total probability of frost is R/L, the probability of last frost occurring before date C is $R/L - 1/Y$, or $(RY-L)/LY$. Hence we have

$$(RY-L)/LY : 1/A :: R : L,$$

from which $A = RY/(RY-L)$.

Case IV. When the probability of frost after date C is equal to the total probability of frost, or $1/Y = R/L$. Here A is infinite, and there is no solution.

Case V. When the probability of frost after date C is greater than the total probability of frost, or when $1/Y$ is greater than R/L. In this case A is negative and there is no solution.

A CORRELATION BETWEEN THE RAINFALL OF NORTH AND SOUTH AMERICA.

By H. HELM CLAYTON.

[Dated: Oficina Meteorológica Argentina, Buenos Aires, Mar. 20, 1916.]

Pursuing a line of research outlined in the Popular Science Monthly (New York) of December, 1901, the writer obtained the average rainfall in the United States between the longitudes of 80° W. and 110° W., which includes all the States except the north Atlantic, the Plateau, and the Pacific coast. This average was compiled from the data published in the bulletin of the Weather Bureau entitled "The Annual Precipitation of the United States for the Years 1872 to 1907," in which the rainfall is given for selected stations nearly equally distributed. Mr. P. C. Day has kindly extended this data to the end of 1914.

The object of the research was to compare the total rainfall with the total crop production, and between the two there is an interesting correlation. There has also been discovered a correlation between this rainfall of central North America and that of central South America as indicated by the outflow in the River Paraná. There appears to be an inverse correlation between these two and the rainfall of Australia. The data are given in Table 1.

TABLE 1.—*Comparison of annual rainfall over the central United States with that over Australia and the mean annual heights of the Paraná at Rosario, Argentina.*

Year.	Mean general rainfall in the United States between meridians 80° and 110° W.		Paraná at Rosario.		Australia.
	Annual fall.	Departure from mean.	Mean annual height.*	Departure from mean.	Percentage of area with rainfall above the average.
	Inches.	*Inches.*	*Meters.*	*Meters.*	*Per cent.*
1900	31.97	+2.11	4.527	+0.792	....
1901	26.75	−3.11	2.998	−0.737	....
1902	30.44	+0.58	3.536	−2.001	....
1903	30.14	+0.28	3.268	−0.467	....
1904	28.08	−1.78	3.807	+0.072	....
1905	34.18	+4.32	5.611	+1.876	....
1906	32.71	+2.85	3.621	−0.114	....
1907	28.77	−1.09	3.634	−0.101	....
1908	30.93	+1.07	4.249	+0.514	33
1909	30.09	+0.23	2.924	−0.811	40
1910	23.63	−6.23	2.837	−0.898	75
1911	28.37	−1.49	3.128	−0.607	25
1912	31.67	+1.81	4.382	+0.647	12
1913	30.80	+0.94	3.664	−0.071	27
1914	29.34	−0.53	3.836	+0.101	11
Mean	29.86.	....	3.735	....	....

* From data kindly furnished me by the Chief of the Hydrometric Section of the Oficina Meteorológica Argentina.

In this table column 1 gives the year; column 2 gives the mean annual rainfall per station in the United States; column 3 gives the departures from the average values; column 4 gives the mean annual river stages at Rosario; column 5 the departures of these from the average; column 6 gives the percentage of the area of Australia over which the rainfall was above the normal. These percentages were taken from a meteorological chart published by Mr. H. A. Hunt, Commonwealth Meteorologist. Unfortunately the data do not go back of 1908.

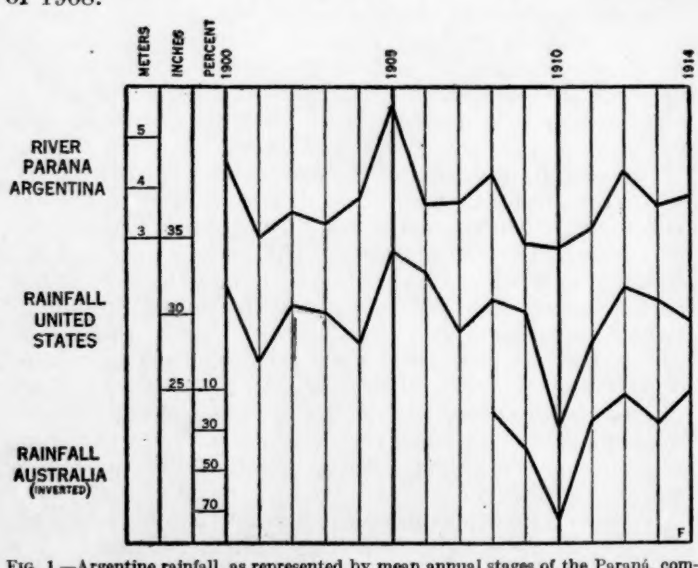


FIG. 1.—Argentine rainfall, as represented by mean annual stages of the Paraná, compared with central United States and Australian rainfalls.

Computing the correlation factor between the departures of annual rainfall in the United States and the departures of the mean river heights at Rosario by the formulas given by Yule in his Theory of Statistics, the correlation is found to be 0.71. The data are plotted in figure 1 and show to the eye the closeness of the correla-

tion. This correlation of rainfall is probably associated with correlations of temperature found by Mossman and Arctowski in the Southern Hemisphere.

In an article on Australian and South American correlations in Symon's Meteorological Magazine, 1913, **48**, Mr. R. C. Mossman gives the data in Table 2, comparing the mean temperature for the months from January to March at Cordoba in central Argentina (lat. 31° 25′ S., 64° 12′ W., height=1,437 feet) with those of Alice Springs in central Australia (lat. 23° 38′ S., long. 133° 37′ E., height=1,926 feet), both stations being located in a strictly continental situation.

Table 2.—*Comparison of mean temperatures at Cordoba, Argentina, and at Alice Springs, central Australia.*

Year.	Mean temperatures, January-March.		Departures from average.	
	Alice Springs.	Cordoba.	Alice Springs.	Cordoba.
	°*F.*	°*F.*		
1897	81.0	72.7	+0.4	+0.9
1898	80.2	71.9	−0.4	−0.7
1899	79.7	71.1	−0.9	+3.2
1900	83.0	75.0	+2.4	+3.2
1901	80.3	71.2	−0.3	−0.6
1902	83.3	74.2	+2.7	+2.4
1903	83.0	72.7	+2.4	+0.9
1904	75.7	67.6	−4.9	−5.2
1905	80.5	69.7	−0.1	−2.1
1906	82.8	72.9	+2.2	+1.1
1907	79.7	72.1	−0.9	+0.3
1908	79.2	70.9	−1.4	−0.9
1909	80.5	72.5	−0.1	+0.7
1910 (?)	79.8	71.4	−0.8	−0.4
Mean	80.6	71.8		

From these figures Mossman deduces a correlation coefficient of 0.89. The temperatures at Alice Springs are the means of maxima and minima, while at Cordoba they are the means of 24 hourly values. The values of temperature are plotted in figure 2, and comparing these with the rainfall variations in figure 1 there is seen to be a similarity between the rainfall and temperature curves in the number of fluctuations and in the times of maxima and minima.

This similarity is even better shown by H. Arctowski's means of consecutive 12 months at Arequipa[1] shown in figure 3.

From these curves one sees that there were maxima of temperature and rainfall about the years 1900, 1902, 1905–6, 1908, and 1912, and minima about the years 1901, 1904, 1907, and 1910. However, the absolute maxima and minima of rainfall and temperature do not coincide very well, except in the case of Arequipa, where the deep minima of 1909–10 coincide with the equally marked minima of rainfall in North and South America and a maximum in Australia.

My earlier researches, published in the American Meteorological Journal,[2] as well as the recent ones of Arctowski, show that maxima and minima of temperature and pressure, as shown by consecutive means of 12 months, do not occur simultaneously everywhere, but oscillate irregularly back and forth over these continents. Yet when the averages over large continental areas are taken, as in the present study of rainfall, there certainly

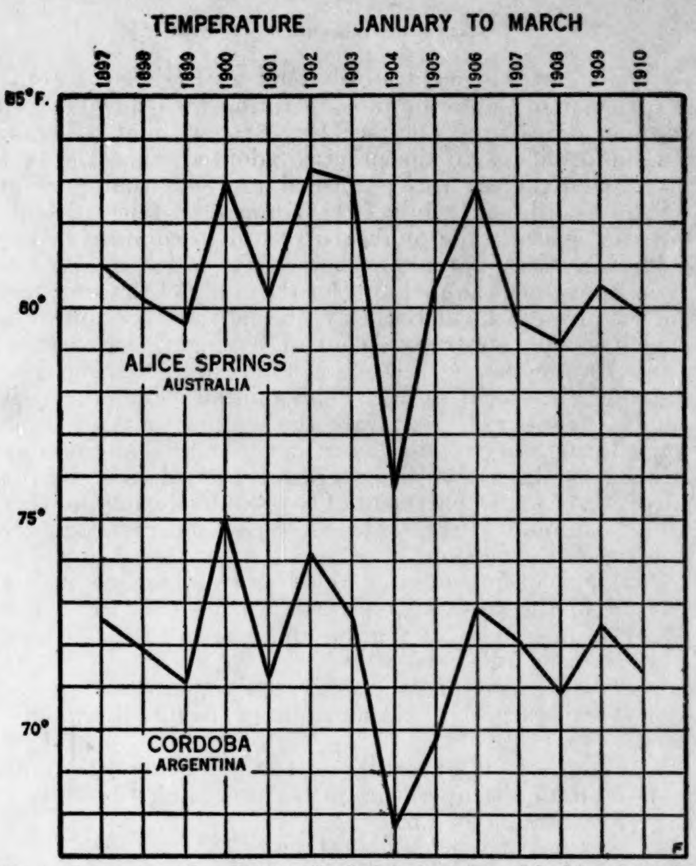


Fig. 2.—Temperatures (Jan.–Mar.) at Alice Springs, Australia, and Cordoba compared.

does appear a similarity on widely separated continents. So striking is this similarity that there can scarcely be a doubt of a common cause of these changes which may

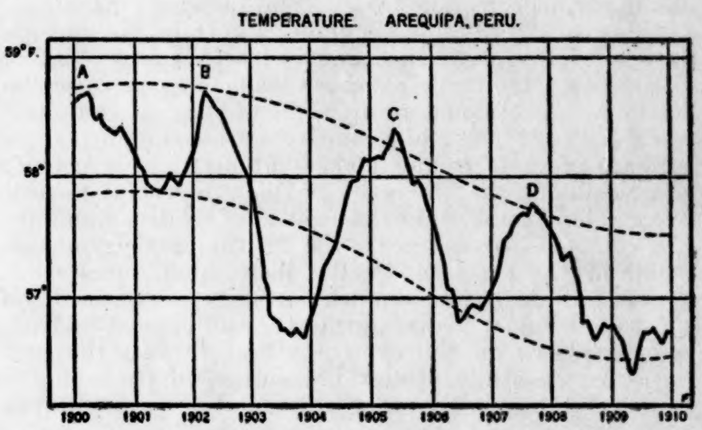


Fig. 3.—Curve of consecutive annual means of temperature at Arequipa, Peru. *A, B, C, D,* pleionian crests alternating with antipleionian depressions. Macrochronic variation shown by the dotted lines. (After Arctowski.)

well be changes in the solar heat, indicated by variations in the number of solar faculæ such as is claimed by Lockyer, Bigelow, and Arctowski.

[1] *See* Annals, New York acad. sci., June, 1914, 24: 43.
[2] *See* Amer. meteorol. jour., Detroit, 1885, 2: 126.

REPORT OF THE METEOROLOGICAL STATION AT BERKELEY, CAL., FOR THE YEAR ENDING JUNE 30, 1914.[1]

By WILLIAM GARDNER REED.

[*Author's abstract* submitted May 24, 1916.]

The meteorological record kept at Berkeley by the University of California in cooperation with the Weather Bureau dates from October 16, 1886, without a break. In conformity with the practice adopted when the first five-year synopsis was published in 1892, that portion of the record before July 1, 1887, has been rejected; this practice permits the published record to conform to the administrative year of the university, which is also the most convenient annual unit for the study of the meteorological phenomena at Berkeley, specially the precipitation which is under subtropical control, having winter cyclonic rains, forming a rainy season beginning in the fall and continuing to the next spring. This rainfall régime makes it almost necessary to separate the annual units at some time during the dry summer rather than at the beginning of the calendar year. The work was carried on under the direction of the Department of Geography during the year ending June 30, 1914. This is the second report under the present direction.[2]

No new equipment was added and no changes in the routine of the station were made during the year. The observations, made at 8 a. m. and 8 p. m., Pacific time, have been as follows:

1. Temperature of the air (dry-bulb thermometer).
2. Temperature of evaporation (wet-bulb thermometer).
3. Maximum temperature in the preceding 12 hours.
4. Minimum temperature in the preceding 12 hours.
5. Pressure of the air.
6. Amount of cloud and weather.
7. Wind direction and estimated velocity.
8. Precipitation in the preceding 12 hours.

In addition to the observation of measurable phenomena at the regular hours of observation, a record has been kept of the general character of each day and the prevailing wind direction from casual observations during the day, of the times of beginning and ending of precipitation, of the occurrence and character of fog and of frost. An attempt has also been made to record miscellaneous and occasional phenomena of interest, although such a record must of necessity be incomplete in the absence of more frequent observations than is usually practicable at the university. The autographic records of air temperature and pressure and of relative humidity are complete for the year; the instrumental errors are small in the cases of all the instruments in service. Terrestrial radiation temperatures were obtained on most of the clear nights during the winter months from several places on the campus; these furnish the first data for the study of the distribution of frost on the campus. This work is, however, largely experimental in character. For each month in which the tipping-bucket gage was in operation maximum rainfall rates have been furnished by the Department of Civil Engineering.

The instruments are all located on the campus of the University of California. The campus is situated on the inner or eastern edge of the coastal plain which forms the eastern shore of San Francisco Bay. The distance from the water's edge to the instruments is about 4 kilometers (2½ miles), and the elevation of this part of the campus is about 95 meters (310 feet). The slope is gentle and nearly uniform from the campus to San Francisco Bay, but immediately east of the campus the Berkeley Hills rise to elevations of over 300 meters (1,000 feet) in less than 2 kilometers (1¼ miles). The Golden Gate is about 20 kilometers (12 miles) west-southwest from the station, and the Pacific Ocean is about 2 kilometers farther westward.

In addition to the routine work of the station, the following studies have received attention:

1. Frost conditions in Berkeley.
2. Temperature comparison between the university campus and the Berkeley High School building.
3. Hydrographic survey of Strawberry Creek.

The first of these studies has been carried on during the year by the writer is a more or less casual manner, although the observations are accumulating for future use. The second is the result of the cooperation of the Berkeley High School with the Department of Geography of the university. The hydrographic survey was carried on during the year as thesis work in the College of Civil Engineering, although the writer assisted in the meteorological aspects of the problem.[3]

A monthly and annual summary of the meteorological record kept at Berkeley during the year ending June 30, 1914, is presented in Table 1. This table includes the same elements as are published for the regular stations of the Weather Bureau in the annual report of the chief, with the exception of automatic wind records, which are not available for Berkeley.

The use of the C. G. S. system of rational meteorological units has been continued for the reasons stated in the previous report.[4]

Table 1 shows the meteorological conditions of the year in a general manner. In Table 2 the extreme temperatures for each month have been compiled from the 27-year record.

In California rainfall data are without doubt the most important of climatic records. Table 3 shows the monthly and accumulated seasonal precipitation and its relation to the average of the whole record for each month of the year 1913–14.

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[1] *Author's abstract* of University of California, Publications in Geography, v. 1, No. 9, pp. 373–439, pls. 45–55, 10 text figs., issued Apr. 10, 1916.

[2] An abstract of the report for 1912–13 was published in the MONTHLY WEATHER REVIEW, Apr., 1914, 42: 164–166.

[3] *See* MONTHLY WEATHER REVIEW, January, 1915, 43: 35–39.

[4] The meteorological units used in this report are defined as follows:

Bar, a pressure equal to an accelerating force of 1 megadyne (1,000,000 dynes) per square centimeter.

Millibar, a pressure equal to one-thousandth of a bar—that is, 1 kilodyne (1,000 dynes) per square centimeter.

Dyne, a force which acting for one second will impart to a mass of 1 gram a velocity of one centimeter per second.

Absolute temperature, the number of degrees above "absolute zero" in units whose length is one one-hundredth of the difference between the boiling point of pure water and the melting point of pure ice under standard conditions. In this system the melting point of ice is 273°A.

Tables for the use of the C. G. S. units and conversions to and from English units may be found in the Smithsonian meteorological tables and this REVIEW, April, 1914, 42: 231.

TABLE 1.—*Meteorological summary, Berkeley, Cal., for the year ending June 30, 1914.*

[H=100.6 m; H_b=98.0 m; h_t=1.5 m; h_r=4.6 m; ϕ=37° 52′ N; λ=122° 16′ W. 120th meridian time.]

Month.	Pressure (sealevel equivalents.)			Temperature.							Moisture.								Cloudiness.	
	Monthly mean (corrected for diurnal variation).	Extremes.		Mean.					Extremes.		Dew point.		Relative humidity.		Vapor pressure.		Precipitation.			
		Maximum.	Minimum.	8 a. m.	8 p. m.	Maximum.	Minimum.	Monthly.	Maximum.	Minimum.	8 a. m.	8 p. m.	8 a. m.	8 p. m.	8 a. m.	8 p. m.	Total.	Maximum in 24 hours.	8 a. m.	8 p. m.
	mb.	*mb.*	*mb.*	°*A.*	°*A.*	°*A.*	°*A.*	°*A.*	°*A.*	°*A.*	°*A.*	°*A.*	%	%	*mb.*	*mb.*	*mm.*	*mm.*	*0–10*	*0–10*
July	1016.0	1021.0	1006.7	288.7	288.3	296.1	285.1	290.6	308	282	285	285	81	82	14.2	14.0	4.8	2.5	5	4
August	1015.2	1021.3	1007.4	289.3	288.9	296.9	286.1	291.5	306	284	286	286	82	86	15.2	15.2	0.8	0.8	6	4
September	1015.6	1020.6	996.6	289.6	289.2	298.7	285.9	292.3	314	283	285	285	76	77	13.9	13.8	......	......	5	3
October	1016.7	1024.0	1005.7	286.6	287.3	296.7	283.6	290.2	308	280	281	282	75	72	11.1	11.3	9.1	9.1	4	3
November	1017.6	1027.1	992.2	283.3	284.4	288.9	281.8	285.4	297	277	281	282	93	88	11.3	11.8	149.4	35.6	7	5
December	1019.2	1027.1	1007.8	280.2	281.7	286.4	278.9	282.6	292	275	279	281	92	91	9.4	10.0	177.3	40.1	6	5
January	1017.8	1033.8	998.9	281.2	282.3	286.7	279.5	283.1	293	275	280	281	95	96	10.2	14.1	323.6	57.9	6	5
February	1019.5	1031.1	996.6	281.2	282.2	289.4	279.7	284.6	294	276	280	281	89	85	9.8	10.9	101.1	45.5	3	4
March	1018.9	1028.4	1007.1	284.5	285.5	293.2	282.2	287.7	304	276	282	282	82	82	10.8	11.7	25.2	23.9	5	4
April	1017.8	1025.0	1003.3	286.2	285.3	292.8	282.2	287.5	303	280	283	283	82	87	12.3	12.3	33.8	14.7	6	5
May	1016.1	1022.0	1010.5	285.7	285.2	291.8	282.8	287.3	297	280	281	284	92	93	13.0	13.0	15.8	5.3	6	6
June	1015.0	1020.6	1006.4	286.5	285.8	292.8	282.7	287.8	303	280	284	284	88	91	13.5	13.4	12.2	8.4	7	5
Year	**1017.2**	**1033.8**	**992.2**	**285.2**	**285.5**	**292.5**	**282.6**	**287.6**	**314**	**275**	**282**	**283**	**86**	**86**	**12.1**	**12.6**	**853.1**	**57.9**	**6**	**4**

Month.	Wind.										Number of days.													
	Prevailing direction.	Number of winds, 8 a. m. and 8 p. m.									Clear.	Partly cloudy.	Cloudy.	Precipitation.		Snow.		Hail.	Dense fog.	Maximum temperature.		Minimum temperature 273° A. or below.	Electricity.	
		North.	Northeast.	East.	Southeast.	South.	Southwest.	West.	Northwest.	Calm.				0.2 mm. and over.	1.0 mm. and over.	Trace or more.	0.2 or more melted.			273° A. or below.	303° A. or above.		Thunderstorm.	Aurora.
July	SW.	0	0	0	0	24	18	5	6	9	14	7	10	2	2	0	0	0	3	0	2	0	0	0
August	S.; SW.	1	0	0	3	33	3	10	1	11	13	12	6	1	0	0	0	0	2	0	1	0	0	0
September	NW.	5	0	0	0	12	10	12	3	18	13	13	4	0	0	0	0	0	2	0	0	0	0	0
October	SW.	4	3	3	3	19	[illegible]	5	2	14	15	10	6	1	1	0	0	0	6	0	0	0	0	0
November	S.	13	2	0	10	19	5	3	2	6	7	10	13	17	12	0	0	0	7	0	0	0	0	0
December	S.	3	4	4	8	28	3	0	2	10	7	8	16	13	12	0	0	0	1	0	0	0	0	0
January	S.	2	0	0	3	40	5	0	0	12	10	3	18	16	15	0	0	1	1	0	0	0	2	0
February	SW.	3	0	2	12	17	3	2	2	15	12	6	10	8	6	0	0	0	2	0	0	0	1	0
March	SW.	3	3	1	7	22	4	2	5	15	16	5	10	3	1	0	0	1	1	0	0	0	0	0
April	S.	6	0	0	3	26	7	2	4	12	12	10	8	7	7	0	0	0	1	0	0	0	0	0
May	SW.	0	0	0	8	18	20	4	4	8	13	8	10	6	5	0	0	1	1	0	0	0	1	0
June	SW.	1	0	0	11	19	14	6	3	6	10	13	7	4	3	0	0	0	2	0	1	0	0	0
Year	**SW.**	**41**	**12**	**10**	**68**	**277**	**101**	**51**	**34**	**136**	**142**	**105**	**118**	**78**	**64**	**0**	**0**	**3**	**29**	**0**	**4**	**0**	**4**	**0**

NOTE.—H=altitude of station (rim of raingage) above sealevel.

TABLE 2.—*Extreme temperatures July 1, 1887, to June 30, 1914.*

Month.	Maximum.		Date.	Minimum.		Date.
	°*A.*	°*F.*		°*A.*	°*F.*	
July	309.3	97.3	7, 1905	278.7	42.3	29, 1899
August	307.1	93.4	22, 1891	281.0	46.4	31, 1905
September	313.8	105.5	16, 1914	280.7	45.9	28, 1905
October	308.2	95.4	1, 1914	277.1	39.3	18, 1905
November	300.8	82.0	16, 1895	273.6	33.0	28, 1905
December	293.9	69.6	24, 1901	272.4	31.0	24, 1905
January	298.0	77.0	26, 1899	269.1	24.9	14, 1888
February	299.4	79.5	18, 1899	271.4	29.2	12, 1905
March	303.6	87.1	17, 18, 1914	274.1	33.9	30, 1905
April	303.3	86.6	24, 1913	275.2	36.0	19, 1896
May	306.6	92.5	26, 1896	277.4	39.9	1, 1899
June	311.4	101.1	6, 1903	278.8	42.4	2, 1903
Year	313.8	105.5	Sept. 16, 1914.	269.1	24.9	Jan. 14, 1888.

TABLE 3.—*Monthly and seasonal precipitation for 1913–14, with averages for 27 years and departures from the averages.*

Month.	Monthly.		Seasonal to end of month.		Average seasonal.		Departure, 1913–14.	
1913.	*Mm.*	*In.*	*Mm.*	*In.*	*Mm.*	*In.*	*Mm.*	*In.*
July	4.8	0.19	4.8	0.19	0.6	0.03	+ 4.2	+ 0.16
August	0.8	0.03	5.6	0.22	1.6	0.07	+ 4.0	+ 0.15
September	......	......	5.6	0.22	16.3	0.65	− 10.7	− 0.43
October	9.1	0.36	14.7	0.58	52.0	2.06	− 37.3	− 1.48
November	149.4	5.88	164.1	6.46	120.8	4.77	+ 43.3	+ 1.69
December	177.3	6.98	341.4	13.44	227.6	8.98	+ 113.8	+ 4.46
1914.								
January	323.6	12.74	665.0	26.18	379.7	14.97	+285.3	+11.21
February	101.1	3.98	766.1	30.16	481.6	18.98	+284.5	+11.18
March	25.2	0.99	791.3	31.15	600.7	23.67	+190.6	+ 7.48
April	33.8	1.33	825.1	32.48	637.5	25.12	+187.6	+ 7.36
May	15.8	0.62	840.9	33.10	666.0	26.24	+174.1	+ 6.86
June	12.2	0.48	853.1	33.58	671.6	26.46	+181.5	+ 7.12
1913–14. Season.	853.1	33.58	853.1	33.58	671.6	26.46	+181.5	+ 7.12

In spite of the difficulties encountered in treating rainfall by cyclones, the importance of such treatment is so great that it is essential for a complete presentation of the climatic data of an extratropical station. The number of cyclones with precipitation at Berkeley which was recognized during the year was 34. Cyclonic rainfall occurred in all months of the year except September. Of the total 853.1 millimeters of precipitation recorded, 850 millimeters has been assigned to particular cyclones. Of the remaining 3.1 millimeters 0.8 millimeter was probably dew. Besides this there was 2.3 millimeters which is, perhaps, of cyclonic origin, although neither the weather maps nor the barograph give evidence of cyclonic conditions.

The average rainfall per cyclone during the year was 16.2 millimeters; the heaviest precipitation in a single cyclone was 120.2 millimeters. In one other cyclone the precipitation approached this amount. The smallest amount of precipitation in any cyclone was 0.3 millimeter, but traces of rain were observed twice with cyclonic cloud, although the barograph trace and weather maps did not clearly show cyclones. The average daily precipitation during the passage of cyclones varied from a maximum of 26.2 millimeters on January 21–22 to a minimum of 0.3 millimeter on May 13–16 and June 24. The total number of days on which cyclonic conditions prevailed was 114, which makes the average amount of precipitation per day of cyclonic control 7.5 millimeters.

The duration of the cyclones was as varied as the rainfall. Subject to possible errors in the separation of cyclones when one closely follows another, the maximum duration of a single cyclone at Berkeley was seven days. The minimum duration of a cyclone with significant precipitation was 12 hours.

A problem closely connected with cyclonic weather control is that of rainfall by rainy days. In figure 1 the rainfall for the year has been presented by rainfall days; the rainfall day at Berkeley is the 24 hours ending at 8 p. m., Pacific standard time.

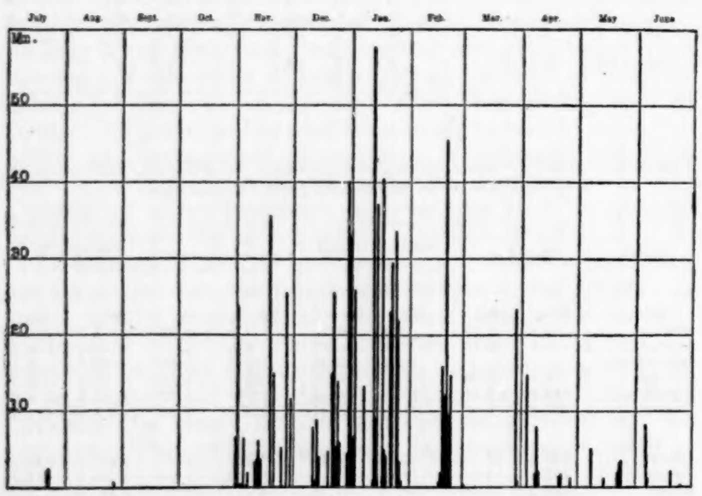

Fig. 1.—Daily precipitation at Berkeley, Cal., 1913–1914.

Figure 1 emphasizes the fact that even during the so-called rainy season the majority of the days are without rain. Although the year was more than usually rainy, only about half the days in the rainy months of November, December, and January had precipitation of 0.2 millimeter, or more; in the other months of the rainy season the proportion of rainy days was even less. The occurrence of rain in periods of several successive days followed by periods without rain, shows very clearly the cyclonic character of the rainfall. The occurrence of the greater part of the rain in the winter months is also shown by figure 1, as is the comparatively dry summer. Noticeable also for the year 1913–14 is the rainless period from August 28 to October 30 and the nearly rainless March. Another feature of the rainfall of Berkeley, which is shown more clearly by figure 1 than in any other way, is the occurrence of light rains during April, May, and June.

The mean annual temperature at Berkeley for 1913–14 was about 288°A., 58°F., with a mean annual range of 10°A., 17°F., and an extreme range of nearly 40° A., 70°F. The mean maximum temperature was 292°A., 67°F, and the mean minimum 283°A., 49°F. The mean monthly range was 22°A., 40°F., the mean daily range 10°A., 18°F. September was the warmest month of the year and December the coldest; no month had a very unusual temperature except March, which was in many respects a characteristic summer month. Frosts occurred from November to March.

The pressure of the water vapor of the atmosphere was in general less than 15 millibars, 11.2 millimeters, or 0.42 inch of mercury; the relative humidity averaged 86 per cent morning and night, the mean dewpoint was about 280°A., 44°F., in the winter and about 285°A., 54°F., in the summer months. The vapor pressure and the dewpoint showed a strong tendency to vary with the air temperature. Nearly 40 per cent of the days were generally clear and nearly 30 per cent generally cloudy; many of the partly cloudy days, specially in summer, had several hours of bright sunshine. Fog was observed on 29 days and the velo cloud, "high fog," on about as many more; this is not abnormal for Berkeley.

The total precipitation for the year was 853.1 millimeters, 33.58 inches, which is 181.5 millimeters, 7.12 inches, more than the average. September, October, March, and May had less than the average rainfall for these months; August, February, and April had about the average amount, and the other months had more than the average of the 27 years of record. The precipitation of January was among the heaviest monthly rainfalls ever recorded at Berkeley. Thunderstorms were observed on four dates; on three days hail fell. There were 78 days with significant precipitation, 0.2 millimeter or more, which is more than the average. In six months of the year there were more than the average number of rainy days for these months, and in six there were less than the average number. The heaviest fall of rain in a single day was 57.9 millimeters, 2.28 inches, on January 12; this is the only day on which as much as 50 millimeters, 2 inches, fell. The precipitation of the year was mainly the result of 34 cyclones, the barometric centers of most of which passed far north of Berkeley, although the cyclones were the controlling factors in the precipitation here; in many other cases the weather control was distinctly cyclonic.

The wind was generally from southerly and southwesterly directions during the year. This is true both for prevailing winds and for the direction at the observation hours. The westerly element was more marked in the summer months. Calm days were rare, four during the year, but at more than one-third of the observation hours no air movement was recorded.

A CENTIGRADE THERMOMETER SCALE PREFERRED.

We take from the report [1] of the annual meeting of the National Academy of Sciences, held in Washington, April 17 to 19, 1916, the following paragraphs of interest to Weather Bureau men.

"A report of the committee [of the National Academy of Sciences] on bill H. R. 528, discontinuing the use of the Fahrenheit thermometer scale in Government publications, was adopted as follows:

Your committee for the consideration of bill H. R. 528, consisting of Messrs. C. G. Abbot, S. W. Stratton, and C. F. Marvin, unanimously reports the following resolution, and moves its adoption:

The National Academy of Sciences shares the desire of scientific men in general for international and world-wide uniformity in units of measurement of all kinds, and with this object in view it favors the introduction of the centigrade scale of temperature, and units of the metric system generally, as standards in the publications of the United States Government.

It must be recognized that considerable initial expense must be incurred by the United States Weather Bureau in changing its apparatus to conform to the proposed act. Furthermore, on account of the more open scale of the centigrade system that bureau will be subject to a continued increased cost of publication, owing to the necessity of printing the first decimal place in order to maintain the present accuracy. The use of negative temperatures and minus signs entails greater liability to errors, and more clerical labor would be required in checking the accuracy of the reports of cooperative observers of the Weather Bureau and in computing monthly and other mean temperatures.

Notwithstanding the foregoing, the academy is in favor of legislation to make the centigrade scale of temperatures the standard in publications of the United States Government, and funds should be made available by Congress to accomplish the desired result.

The academy favors bill H. R. 528, "to discontinue the use of the Fahrenheit thermometer scale in Government publications," but recommends that it be amended by the addition of the following:

"SEC. 4. When in the publication of tables containing several meteorological and climatic elements the use of data in centigrade temperatures leads to manifest incongruities, the Chief of the Weather Bureau is directed to publish related data in such units as are necessary to make the tables homogeneous and to secure international uniformity as far as practicable.

"SEC. 5. Nothing in this act shall prevent the use of the absolute centigrade scale of temperature in publications of the Government."

MARCELLUS HARTLEY MEMORIAL MEDAL, 1916.

[On April 18, 1916, the National Academy of Sciences, meeting at Washington, D. C., awarded a Marcellus Hartley medal "for eminence in the application of science to the public welfare" to Prof. Cleveland Abbe in recognition of his services in connection with the foundation and organization of the United States Weather Bureau. The nominating speech was made by Prof. William Morris Davis, and the acceptance was by Prof. Charles Frederick Marvin for Prof. Abbe, who was absent on account of ill health.

The award of the Hartley medal to Cleveland Abbe is the first time this medal has gone to one of the members of the National Academy of Sciences.

By the courtesy of the National Academy of Sciences it is possible to publish here the remarks made on the occasion, remarks of historic value as indicating the character of the medallist and also as recording some little-known details in the history of the Weather Bureau.—C. A. jr.]

REMARKS BY WILLIAM MORRIS DAVIS.

Among the gratifying duties of the National Academy of Sciences is that of awarding certain medals in recognition of notable achievement. One of our medals, founded by a daughter in memory of her father, Marcellus Hartley, of New York, is to be given for "eminence in the application of science to the public welfare." I am glad, Mr. President, that this medal is awarded for *eminence* in the application of science, for if it were to be awarded for *prominence*, it never could have been given to a man so modest, so retiring, so diffident, as Cleveland Abbe. We all have had a warm pleasure in voting to approve the discernment of our committee in nominating this gentle man, who has so long labored quietly, without ostentation, never intruding himself upon public notice for the display of his learning, to be the recipient of a medal for real eminence in the work that he has done for his country's good.

It is singular and regrettable that, although we have a large and varied assortment of weather, sometimes, indeed, an oversupply of it, spread across the continent from ocean to ocean, we have had but few weather men—meteorologists—of high standing. The devotees of the subject have too often perpetuated an unscientific, astrological habit of mind, elsewhere extinct. Only about six of them have attained academic rank. Redfield and Espy were contemporaries and competitors in the first half of the nineteenth century—Redfield, a careful observer and a cautious theorizer, a true inductive philosopher, to whom the world owes the first demonstration that West Indian hurricanes are gigantic whirlwinds; Espy, an equally good observer but a bolder theorizer, whose keen deductions regarding atmospheric convection and the associated adiabatic changes of temperature in air currents having a vertical component excited less admiration in our own then unlearned country than in more learned countries abroad. The work of these eminent Americans was done before the formation of the National Academy, but Redfield was a member of the American Academy of Arts and Sciences in Boston, and Espy of the American Philosophical Society in Philadelphia.

Long before their time lived the most famous of all American meteorologists, Benjamin Franklin, who not only established the identity of lightning and electricity about the middle of the eighteenth century, but proved at a somewhat earlier date that our northeast storms come from the southwest, and thus laid the basis of modern weather predictions. His name is still worthily celebrated every year by the famous academic society that he founded.

Redfield and Espy were followed in the second half of their century by Loomis and Ferrel, in whom the contrasts of the two earlier masters were repeated. They were both members of this Academy. Like Redfield, Loomis was faithfully inductive; it was he who first analyzed and generalized the great body of observations that were recorded on the early weather maps of the Signal Service. He thus established a large number of values regarding the behavior of winds, the changes of temperature, and the fall of rain or snow in the traveling areas of high and low pressure that sweep eastward through the Temperate Zone; and in this fundamental work he has not, I regret to say, as yet been followed by a worthy successor. Like Espy, Ferrel was inventively deductive; he directed his extraordinary native powers of mathematical analysis to such problems as the general circulation of the atmosphere and the vortical currents of cyclones and tornadoes, and made an enduring mark upon them. The autobiography of this self-taught farmer's boy is a touching story of emerging genius.

During an intermediate period Maury systematized the reduction of meteorological observations at sea; Joseph Henry did much to encourage systematic meteorological observation on land; and Coffin, utilizing all available records from lands and seas, compiled his great work on the Winds of the Globe; but the impress of these three men on the scientific interpretation of atmospheric phenomena was not so profound as that of Redfield and Espy before them or of Loomis and Ferrel after them.

[1] Proc., Nat'l Acad. Sci., May, 1916, v. 2, No. 5, p. 304.

Cleveland Abbe was for a time the academic contemporary of the last two named, as he is now almost their solitary meteorological successor in this country; for of others, we have lost Lawrence Rotch, founder and director of that admirable institution, the Blue Hill Meteorological Observatory, near Boston, by his untimely death four years ago.

It is the practical turn which Abbe gave to his scientific studies nearly 50 years ago that we celebrate to-night, for it was then, when he was a young man in Cincinnati in 1868, that he first put into execution in this country a scheme of daily weather prediction, based upon the telegraphic concentration of widespread synchronous observations. Would that he could be with us this evening to tell the story of that novel undertaking, but in his absence I may perhaps advert to certain matters which might embarrass him were he with us. His private enterprise was soon superseded by the establishment of a national meteorological bureau at the hands of Gen. A. J. Myer, Chief Signal Officer of the Army; and thereupon Abbe was brought to Washington as the one expert of the country qualified to set the new service on its scientific feet. Here for all these years since 1870, first in the War Department, later in the Department of Agriculture, he has been the senior scientific adviser of the Weather Service, and thus his influence in practical meteorology over the length and breadth of our land has been enormous. Although his hand has taken its turn with others at the exacting duty of daily prediction and has carried on its assigned share of the over-great volume of routine tasks that are conventionally customary in meteorological institutions, his heart has never ceased to turn to or to yearn for the more original efforts of scientific investigation. More characteristic of the man than his work in such necessary matters as the construction of tables for the daily routine of reducing barometric observations to the level of the sea, or the preparation of instructions for reducing the daily routine of meteorological duties to the level of the observer, was his translation of several difficult mathematical memoirs on the circulation of the atmosphere, published and distributed by the Smithsonian Institution, out of which I fancy he had greater enjoyment than anyone else—though that is not saying much. Evidently enough, therefore, the one great practical scheme of daily weather prediction, that has made him deservedly eminent in the application of science to the public welfare, did not divert his mind from unpractical scientific research. He has always willingly turned his attention to new problems and become happily engrossed in them when opportunity offered, yet he has ever been ready to interrupt his work and to draw on his great store of learning to answer questions from inquirers of all degrees. I fear that his scientific spirit has not at all times been happy under the regulations that are presumably appropriate in a large governmental bureau, and that his sensitive nature has sometimes been bruised by the arbitrary discipline of wholesale official service. But his is a buoyant disposition, and cheerfulness has long been his dominant quality.

We all regret his absence this evening. As he can not be with us in the flesh, let us draw him forth in spirit from his self-effacing retirement; let us see in imagination the genuine surprise that he would feel on learning of our action in selecting *him* for a high distinction; let us through our memory of other years enjoy the genial smile with which he would return our greeting. Mr. President, it is a great pleasure most cordially to present *in absentia* Prof. Cleveland Abbe, that he may receive from you, through the hands of his former pupil, his present superior officer and his constant friend, the Chief of the Weather Bureau,[1] the medal which he so richly deserves.

REMARKS BY PROF. C. F. MARVIN.

Mr. President, members, and guests of the National Academy:

Words fail me to speak fully of my deep feeling on this occasion. I can not tell how much I appreciate this great privilege and honor that devolves upon me in accepting this medal for Prof. Abbe, with whom I have been intimately associated for more than 30 years. During this time we have worked side by side, so to speak, and I have learned not only to hold him in the greatest esteem because of his eminent work in science, but also to love him dearly because of those modest, gentle, and beautiful qualities of character that were just now set out in such touching fashion by Prof. Davis. His whole life and energies have been devoted to the advancement of the science of meteorology; he has thought only of its problems and how he could encourage and induce others to unravel its perplexities, and has never given any thought to himself. These characteristics, it seems to me, add greatly to the eminence Prof. Abbe has attained, the eminence unsought by himself but bountifully bestowed upon him by others. Only a short time ago, when it was learned that he had been awarded this medal and he had requested me to receive it for him, I asked him to tell me what to say for him in acceptance. Without a moment's hesitation he replied: "Oh, they do too much for me, they must not forget Henry, Espy, Ferrel, Lapham, and others."

I am only an humble worker in the domain of science and I could never hope to deserve so great an honor as a medal like this for myself. Therefore this is the greatest event in my life, and I feel deeply the privilege and honor of receiving this medal for Prof. Abbe, whom I love and esteem so highly. Just this morning I received a note from Prof. Abbe giving an account, in his own words, of his early work leading to the creation of the weather forecasting service in the United States.

If you will permit me, Mr. President, I should like to read what Prof. Abbe says. It will take but a few minutes and I believe the members of the Academy will be glad to hear from him.

A SHORT ACCOUNT OF THE CIRCUMSTANCES ATTENDING THE INCEPTION OF WEATHER FORECAST WORK BY THE UNITED STATES.

By CLEVELAND ABBE.

My boyhood life in New York City had impressed me with the popular ignorance and also with the great need of something better than local lore and weather proverbs. The knowledge of the sailors and farmers whom I met seemed to me unsatisfactory. The popular articles in the New York daily papers, by Merriam, Espy, Joseph Henry, and others—notably Redfield and Loomis—had by 1857 convinced me that man should and must overcome our ignorance of the destructive winds and rains. It was in the summer of 1857 or 1858 that I read the beginning of the classic article by William Ferrel in the Mathematical Monthly. I realized that he had overcome many of the hidden difficulties of theories of storms and winds; from that day he was my guide and authority. During 1858–1864, in the practice and study of astronomy with Brünnow at Ann Arbor, Mich., and Gould at Cambridge, Mass.,

[1] Charles Frederick Marvin.

I was impressed with the unsatisfactory state of our knowledge of atmospheric refraction. Two years later my experience at Poulkova, Russia, and at our Naval Observatory, Washington, seemed to justify my conclusion that astronomers who would improve their meridional measurements must investigate their local atmospheric conditions more thoroughly and to this end must have numerous surrounding meteorological observations. Hence in my inaugural Cincinnati address of May 1, 1868, I stated that with a proper system of weather reports the public need of forecasts could be met and that astronomy could also be benefited.

This suggestion was taken up by Mr. John A. Gano, president of the local chamber of commerce; a committee met me, approved my plans, and promised the expenses of a first trial. I had the total solar eclipse of August 7, 1869, on my hands, but immediately began to arrange for 40 voluntary meteorological correspondents. On my return from observing the eclipse at Sioux Falls City, I stopped at Chicago and formally invited the Chicago Board of Trade to join in extending the Cincinnati system to the Great Lakes, but this invitation was declined by the Chicago Board of Trade. An editorial in a Chicago evening paper of Monday, August 16, 1869, stated the scientific basis of our observatory work. I returned at once to Cincinnati, issued the first number of the Cincinnati Weather Bulletin promptly, as promised, on September 1, 1869; it contained a few observations telegraphed from distant observers and the "probabilities" for the next day. This bulletin was posted, in my own handwriting, prominently in the hall of the chamber; but I soon found below my misspelled "Teusday" a humorous line by Mr. ——— Davis, the well-known packer: "A bad spell of weather for 'Old Probs.'" This established my future very popular name "Old Probs."

My forecasts were treated very kindly by all. I had anticipated a slow increase in accuracy; I ventured to write my father in New York City "I have started that which the country will not willingly let die." I wrote a short note to the New York Times (or Tribune) telling them how useful we could be to their shipping. On September 3, 1869, I even ventured to offer a daily telegram by the French cable to Le Verrier as founder of the Bulletin Hebdomadaire de l'Association Scientifique, and who could fully sympathize with my hopes and plans. He realized the breakers ahead of me better than I. My daily telegram from Milwaukee came from the well-known Smithsonian observer and author, Prof. Increase Allen Lapham. He had known and appreciated the works of Espy, Redfield, Loomis, and others, but he had become absorbed in other studies; he now urged the local Milwaukee society to do something for Lake Michigan. His friends were just about to go to the Richmond meeting of the National Board of Trade; there they met William Hooper and John A. Gano. These merchants of Cincinnati found that they had the same idea as H. E. Paine, of Milwaukee, i. e., that the Federal Government should develop the Cincinnati enterprise and make it useful to the whole country. The National Board of Trade indorsed this idea; Prof. Lapham, of Milwaukee, drew up some statistics of storms and destruction on the Lakes; the Hon. Halbert E. Paine prepared Public Resolution No. 9; we each put our shoulders to the wheel and behold on February 9, 1870, the Secretary of War was authorized to carry out this new duty. I had spent a year in finding stations, voluntary observers, and telegraph facilities; every old classmate or friend of progressive meteorology had helped the new idea. The work had now passed out of my hands. I saw that I must soon go back to the observatory work that I had undertaken—the rejuvenation of the famous old Cincinnati observatory—but there was much more to be done. A letter from the Chief Signal Officer, United States Army, Gen. Albert J. Myer, asked for all possible cooperation. The officials of the Western Union Telegraph Co. offered the observatory the same free daily weather reports that they had for 20 years been giving to the Smithsonian Institution and the daily press; so I continued temporarily to make and publish the Cincinnati Bulletin, but in a much simpler form and without forecasts. This continued until May 10, 1870, when I was married, and the preparation of the midnight bulletin passed over to the officials of the local telegraph office. It was continued in this shape until November, 1870, when the tridaily bulletins of the Army Signal Service began. With the help of ——— Williams, who was in charge of the Western Union office, I printed in October, 1869, a code of cipher, and should have used this code for economy, had not the Joint Resolution of February 9, 1870, anticipated further reports by my own stations. This code was subsequently greatly improved by Weather Bureau men, and particularly by Gen. A. W. Greely, and it is still in use.

The manifolded duplicate copies and the printed copies of the daily Cincinnati Observatory Bulletin were distributed until the chamber of commerce no longer needed to support it; then Mr. Williams devised a simple form of manifold map that was a great improvement on my original tabular form of daily reports. This map was soon adopted by the Signal Service, but was itself displaced in turn by the present handsome daily lithographed chart. Without the help of Armstrong and Williams and the new manifold method patented by J. Jones we could not have promptly responded to the needs of our friends.

By November, 1870, I had gone to New York and prepared to go as astronomer on one of the Panama Canal surveys, but I gave this up and should have returned soon to Cincinnati had I not, in December, received a letter from Gen. Myer stating that he wished to see me. My work with him in the Weather Bureau of the Army Signal Service began January 3, 1871. After a month's practice it was decided that my forecast would evidently more than fill the popular expectations and tridaily publications began at once. The term "probabilities" then became official, as it had begun in 1869, and in those days it was appropriate; but we have long since used and accepted the word "forecast."

The subsequent development of the service under Gens. Myer, Hazen, and Greely, and Profs. Harrington, Moore, and Marvin may be gathered from their special or annual reports. The service has been greatly favored by the hearty cooperation of many men of knowledge, skill, and enthusiasm.

USE OF THE TERM "INDIAN SUMMER" IN 1778 ?

It is gratifying to learn from a recent paper by Mr. Horace E. Ware,[1] read before the Colonial Society of Massachusetts that the search for facts bearing on the origin of the term "Indian summer" as applied to certain phases of our fall weather, keeps alive.

Mr. Ware's paper cites a poem of 1815, by Philip Freneau, as the first appearance of the term in *poetry;* he also quotes Mrs. Sigourney's poem on the subject, written before and published in 1849.

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[1] *Ware, Horace E.* Notes on the term "Indian summer." Pub., Colonial Soc. of Mass., Cambridge, Mass., 1916, 18: 123-130.

In the discussion of Mr. Ware's paper Mr. Albert Matthews remarked that while heretofore[2] the earliest known instance of the term "Indian summer" occurred in the Journal of Maj. Ebenezer Denny while at Le Bœuf, near the present city of Erie, under date of October 13, 1794, he could now quote an example earlier certainly by 7 years and possibly by 16 years. Mr. Matthews continues as follows:

In a letter dated "Germanflats, 17 janvier 1778," Crevecœur gives a "Description d'une Chute de Neige, Dans le Pays de Mohawks, sous le rapport qui interèsse le Cultivateur Américain," in which occurs the following passage:

"Les grandes pluies viennent enfin & remplissent les sources, les ruisseaux & les marais, pronostic infaillible; à cette chûte d'eau succède une forte gelée, qui nous amène le vent de nord-ouest; ce froid perçant jette un pont universel sur tous les endroits aquatiques, & prépare le terre à recevoir cette grande masse de neige qui doit bientôt suivre: les chemins auparavant impracticables, deviennent ouverts & faciles. Quelquefois après cette pluie, il arrive un intervalle de calme & de chaleur, appelé l'*Eté Sauvage* ce qui l'indique, c'est la tranquillité de l'atmosphère, & une apparence générale de fumée.—Les approches de l'hiver sont douteuses jusqu' à cette époque: il vient vers la moitié de novembre, quoique souvent des neiges & des gelées passagères arrivent longtems auparavant."[3]

TRANSLATION.

At last come the heavy rains, filling the springs, the creeks (ruisseaux), and the marshes, an infallible sign; following this fall of water comes a severe frost brought to us by the northwest wind; this piercing cold builds a universal bridge over the watery places, and prepares the land for that great mass of snow which should soon follow it; the roads, which have been impassable heretofore, become open and convenient. Sometimes the rain is followed by an interval of calm and warmth which is called the *Indian summer* (l'Eté Sauvage); its characteristics are a tranquil atmosphere and a general smokiness. Up to this epoch the approaches of winter are doubtful; it arrives about the middle of November, although snows and brief freezes frequently occur long before that date.—C. A., jr.

"Germanflats" is the present Herkimer, N. Y. The author was so careless about certain matters that we can not be sure that his letters were actually written at the dates assigned, but the work from which the passage is cited was published in 1787.[4]

PROF. KITTREDGE'S THEORY.

While on this subject of Indian summer it may be of interest to refer to yet another effort to explain the origin of the term. Prof. George L. Kittredge[5] some years ago discussed the question and offered several suggestions. He thinks, for example, that it is too far-fetched to explain "Indian summer," as haziness which was originally due, in part, to brush and forest fires kindled by the American Indians in November.

Far more reasonable is the conjecture that the name alludes to the proverbial deceitfulness and treachery of the natives. * * * Or possibly we should think rather of their equally proverbial instability. Nothing is more fickle than the weather in Indian summer; though this is a quality that might be predicated of our weather in general. * * *

Or, finally, * * * it is conceivable that Indian summer was at first equivalent (among the earliest English immigrants) to "*fool's summer.*" If so, we seem to have a parallel to the "Old Women's Summer" of the Germans, and it may be also to the "go-summer" of the Scots, if this is a corruption of "Goose summer," as scholars suppose. * * * Nothing impressed the settlers more than the folly of the red men in certain matters. * * * "Fool's summer," though not pretty, would be appropriate enough, and would range well with "fool's gold" for iron pyrites, "fool's parsley" for the poisonous lesser hemlock, and *ignis fatuus*, or "fool's fire," for the will-o'-the-wisp.

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[2] See his paper in this REVIEW, January and February, 1902, 30: 19-28, 69-79.

[3] Lettres d'un Cultivateur Américain * * * depuis l'Année 1770 jusqu'en 1786, par M. St. John de Crèvecœur, Traduites de l'Anglois, Paris, 1787, i 294. The description fills pp. 289-314.—*A. Matthews.*

[4] In his Letters of an American Farmer, published in London in 1782, Crèvecœur does not mention the Indian summer. My attention was called to the passage in the text by Mr. Franklin B. Sanborn's paper on St. John de Crèvecœur, the American Farmer (1735-1813), printed in 2 Proceedings Massachusetts Historical Society, xx, 32-83. Mr. Sanborn shows that Crèvecœur was often inaccurate, remarking in one place: "But dates were never St. John's forte. He misstated the ages of his children by two years, and dedicated the French edition of his Lettres d'un Cultivateur Américain to Lafayette from Albany, 17 mai, 1781, though at that date he was in England" (p. 34, note: cf. pp. 36, 37, note, 45, 52-53, 73-74).—*A. Matthews.*

[5] *Kittredge, George Lyman.* The Old farmer and his almanack. Boston. Wm. Ware & Co., 1904. xiv, 403 p. illustr. 8°. N. B., pp. 191-198.

NEED FOR PAN AMERICAN METEOROLOGICAL COOPERATION.

[In the General Report on the Final Act of the Second Pan American Scientific Congress, held in Washington, Dec. 27, 1915-Jan. 8, 1916, prepared by Mr. James Brown Scott, reporter general to the congress, we find the following commentaries on articles 5 and 6 of the resolutions and recommendations (pp. 59-61.]

Article 5 [recommends that] proper steps and measures be taken to bring about in the American Republics a *general use of the metric system* of weights and measures, in the press, magazines, newspapers, and periodicals, in educational and scientific work, in the industries, in commerce, in transportation, and in all the activities of the different governments.

To the citizens of the Latin-American Republics this article will seem well-nigh meaningless, for in the Western Hemisphere the English system of weights and measures obtains only in the United States and the English-speaking colonies, whereas the remaining American republics and the greater part of the Eastern Hemisphere use the metric system. Measures and weights are, however, an important part of the vocabulary in international relations. The English is not nearly so convenient and simple as the metric system, either in commercial or scientific work. The use of the English system in the United States is one of the important obstacles, in the opinion of the American delegates, to a closer commercial and scientific intercourse and cooperation between the United States and the other American Republics. Therefore, the adoption of the metric system by the United States would be a great benefit economically to the general public, and it is believed that it would not be without importance in promoting good will and mutual understanding.

ARTICLE 6 [the congress] confirms the resolution recommended to the American Republics by the First Pan American Scientific Congress regarding *the installation of meteorological organizations* to serve as a basis for the establishment of a Pan American meteorological service, and expresses the desire that the Republics not yet possessing organized meteorological services establish such as soon as may be practicable.

As questions of international importance, the various topics under meteorology and seismology were considered in the Second Section of the congress. The needs especially of the organization of governmental services for continuous observation of atmospheric and terrestrial phenomena by means of common methods, intercomparable apparatus, and common units were dwelt upon. Much attention was given to the modes of organization and conduct of existing weather bureaus, to methods of forecasting weather, and to the increasing importance of the application of these as an aid to agriculture, navigation, and land transportation of perishable products. Much attention was given also to consideration of secular phenomena in meteorology and to their effects in the habitable as well as in the uninhabitable parts of the globe.

One of the most interesting topics considered as a by-product of the work of the Second Section was that of the desirability of forming an unofficial international association of meteorologists and seismologists for the mutual exchange of ideas and experience arising from these sciences. It was thought that such an organization might accomplish for meteorology and seismology results similar to those which have proved highly beneficial during the past two centuries in the [other] physical sciences.

It will be observed by persons familiar with the Pan American scientific congresses, and, indeed, it is expressly stated in the recommendation itself, that the

importance of the present recommendation has been hitherto recognized and called to the attention of the American countries by the First Pan American Congress; so that the recommendation in question is in reality a reaffirmation of the resolution of the First Pan American Scientific Congress, recommending as most desirable the establishment of official meteorological and seismological services in countries which have not yet established such agencies for the advancement of knowledge of our planet and for direct aid to agriculture, transportation, and sanitation. It is to be hoped that a recommendation urged by two scientific congresses of the Americas will be carried into effect, as it would not have been proposed in the first instance, had its advisability not been apparent, and it would not have been reaffirmed by the present congress unless it were considered, upon reflection, highly desirable. For this reason the congress, in making the recommendation, expressed the hope that the services would be established where they do not exist as soon as may be practicable.

SYMONS MEMORIAL MEDAL FOR 1912.

The Symons Memorial Gold Medal, which is awarded biennially by the Royal Meteorological Society of England, was presented to Prof. Cleveland Abbe at the annual general meeting on January 17, 1912. As this event in the history of the Weather Bureau has never been recorded by the MONTHLY WEATHER REVIEW, we reprint the official report of the proceedings as published in the Quarterly Journal of the Royal Meteorological Society (London), 1912, **38**: 156–7.

PRESENTATION OF THE SYMONS MEMORIAL GOLD MEDAL.

The *President* [Dr. H. N. Dickson] said that it now fell to him to perform one of the most pleasant duties connected with his office, the presentation of the Symons Gold Medal. He would ask Prof. Cleveland Abbe to accept this Medal, but the Secretary would first read the Extract from the Minutes of the Council concerning this award.

The *Secretary* read the following extract from the minutes of the Council Meeting of November 15, 1911:

"Prof. Cleveland Abbe was born on December 3, 1838, at New York. He began active scientific work as a mathematical lecturer, but early in the sixties he joined the U. S. Coast and Geodetic Survey. He was resident at Pulkowa, 1864–1866, which was then under the Directorship of the younger Struve. Abbe returned to the United States and became assistant at the U. S. Naval Observatory. In 1868 he was appointed Director of the observatory at Cincinnati, into which he infused new life. He joined the Weather Service of the United States in 1871, and it is in connection with that organization that his great life-work has been performed.[1]

"Apart from a large amount of official work, evidence of which may be found in the publications of the Weather Bureau, he is notable mainly for (1) his collection of papers on the *Mechanics of the Earth's Atmosphere*, which are today indispensable in work on the dynamics of meteorology. Volume I was issued in 1891 and Volume II in 1908;[2] (2) his *Treatise on Meteorological Apparatus and Methods* issued in 1888. This is a historical and practical account to which even the meteorologist of the twentieth century may turn for instruction; (3) his *Preparatory Studies for Deductive Methods in Storm and Weather Predictions*, issued in 1890; (4) his articles on Meteorology in the Encyclopædia Britannica, which are no doubt well known to all Fellows of the Society.

"Professor Abbe was one of the first to realize the importance of experimental investigations of atmospheric radiation, and it was largely due to his enterprise that the well-known researches of Hutchins and Pearson were undertaken. The importance of this work has been recently emphasized by its application to the explanation of the isothermal condition of the upper atmosphere. Professor Abbe has contributed, therefore, to instrumental, statistical, dynamical, and thermodynamical meteorology, and forecasting. He has, moreover, played throughout the part not only of an active contributor, but also of a leader who drew others into the battle and pointed out the paths along which attacks might be successful.

"He is a Fellow of the Royal Astronomical Society, a member of the National Academy [of Sciences of the United States], and an Honorary Fellow of our own Society."

The *President* then said:

"Professor Abbe, we have listened to the statement of the Secretary setting forth the reasons which have led the Council to award you the Symons Gold Medal on this occasion. I do not think it is necessary or desirable to add to what has been already stated by any further expansion of the points which have been set forth. Every member of the Society is sensible of his indebtedness to the work which you have done in the past in connection with our science. I may perhaps be permitted to add on behalf of those members of the Society who have had the privilege of becoming personally acquainted with you, our sense of the very great debt we owe to you for personal encouragement. I remember the occasion some five and twenty years ago, on which I came, a very raw and budding meteorologist to Washington, and had the privilege of enjoying the hospitality which you so generously offered to those working in the subject; and I remember the strong stimulus which I received from you at that time. There are very many other meteorologists who must be conscious of owing to you a similar debt. It gives me very great pleasure, Sir, to offer you, on behalf of the Society, this Gold Medal."

Professor Cleveland Abbe said that it gave him the greatest pleasure to have his name associated with that of their dear friend and colleague, George James Symons. He could not express his emotion, but could only thank them most sincerely for the honour they had conferred on him in awarding him the Medal. This event will always be to him a stimulus to future labours. They are all brothers in science, and he was greatly touched to hear from the account read by the Secretary, that they had so closely watched his career and labours in a science of which they had not yet reached the end.

[1] See in this connection the personal reminiscences by Professor Abbe, on page 206 of this issue of the REVIEW.

[2] This was his "Collection of translations. Third Collection"; the manuscript was ready for the printer in September, 1908; he finished the proofsheets in April, 1910, and the volume was issued by the Smithsonian Institution in June, 1910.—C. A., jr.

SECTION III.—FORECASTS.

FORECASTS AND WARNINGS FOR APRIL, 1916.

By EDWARD H. BOWIE, Supervising Forecaster.

[Dated: Weather Bureau, Washington, May 19, 1916.]

During the first six days of the month the barometric readings were higher than normal over eastern and southern Alaska, and after the 20th readings were again much above the normal over the entire Alaskan area; in the interval from the 7th to the 19th, inclusive, there was a prolonged depression of the barometer. The reports from Honolulu show a steady pressure above the normal from the 1st to the 19th and a period of subnormal pressures from the 19th to the 30th, inclusive. The subpermanent area of high barometer over the Atlantic Ocean, as shown by the barometer readings at the Azores, was well above the seasonal average from the 3d to the 19th, inclusive, and ill-defined before and after these dates. In the vicinity of the Bermudas, the pressure fluctuated frequently but was near or slightly above the normal in this region during the month.

As might be expected from the variations in the great centers of action over the middle latitudes of the Atlantic Ocean and the Alaska and Aleutian Islands area, the migratory low pressure and high pressure systems shown by the daily weather maps of the United States and southern Canada, were not confined to any particular region as to their first appearance on these charts nor did they follow well-defined paths. The lows were 14 in number, 5 of which belonged to the Alberta, 4 to the Colorado, 1 to the South Pacific, 2 to the East Gulf, 1 to the South Atlantic and 1 to the Central Type. The highs were 11 in number and of these 7 first made their appearance off the Pacific coast north of San Francisco, 3 entered the United States from the western Canadian Provinces and 1 formed over the northern Rocky Mountain region.

WASHINGTON FORECAST DISTRICT.

On the 1st of the month a LOW of considerable intensity was central over Texas, whence it moved eastward across the Gulf States to the Carolina coast by the morning of the 4th, and from this region its center traveled north-northeastward off the Atlantic coast to Newfoundland during the following 48 hours. This disturbance caused strong shifting winds on the east Gulf coast during the 2d, warnings of which were ordered the morning of the 1st on the Mississippi, Alabama, and northwest Florida coasts. This was the only storm warning required on the east Gulf coast during the month. On the morning of the 4th when this storm was central off Cape Hatteras, storm warnings were ordered on the Atlantic coast from Delaware Breakwater to Boston, and during the afternoon and night of this day winds of verifying velocity occurred in the region where warnings were displayed. As the storm advanced rapidly, the duration of the storm winds was not prolonged and no damage to shipping occurred.

The next low of importance east of the Mississippi River formed over the central Rocky Mountain region on the 5th, advanced southeastward to Texas on the 6th, moved eastward across the Gulf States during the 7th, and during the 8th advanced rapidly northeastward. On the morning of the 9th, the center of this disturbance was near Cape Cod, where the pressure was as low as 29.34 inches. When this storm was central over the Carolinas storm warnings were ordered for the Atlantic coast from Delaware Breakwater to Eastport, Me., and winds of gale force occurred within the succeeding 36 hours in the region where warnings were displayed. Moreover, strong westerly winds occurred on the east Gulf and south Atlantic coasts in connection with this disturbance, but as they were not of sufficient force to justify storm warnings, special advices for the benefit of small crafts were sent these regions at the time the storm was passing through the Gulf States. This low was followed by an extensive area of high pressure from the Northwestern States, and as it advanced southward over the Gulf and South Atlantic States it was attended by general frosts on the 9th, 10th, and 11th in these regions, excepting the Florida peninsula. Frost warnings were widely disseminated the morning of the 8th in the east Gulf States, Georgia and South Carolina; the morning of the 9th in the east Gulf and South Atlantic States, except the Florida peninsula, and on the same day warnings of frosts and freezing temperature were issued for Tennessee, the Ohio Valley and the Middle Atlantic States; on the morning of the 10th frost warnings were repeated for the Middle Atlantic and South Atlantic States, except the Florida peninsula and the upper Ohio Valley.

During the night of April 13 there was a rapid development of storm conditions within a region of low pressure that prevailed over the Great Lakes, and on the morning of the 14th, when the center of the disturbance was over the lower Lake region, storm warnings were displayed on the Atlantic coast from Norfolk, Va., to Eastport, Me. The storm under consideration moved southeastward from the lower Lakes and the evening of the 14th its center was near Cape Cod, where the pressure was 29.20 inches. Winds of gale force occurred the afternoon and night of the 14th along the Atlantic coast north of Cape Hatteras. The highest velocities, in miles per hour, were as follows: Norfolk, 60 west; Washington, 44 northwest; Delaware Breakwater, 68 northwest; Sandy Hook, 44 northwest; New York, 72 northwest; Block Island, 46 northwest; and Nantucket, 48 northeast.

On the 16th a low of marked intensity was over the Great Lakes, and storm warnings were displayed on the Atlantic coast from Sandy Hook to Cape Cod; but the center of the Great Lakes storm kept well north of the St. Lawrence Valley and the expected storm winds did not occur. The display of warnings was ordered discontinued the morning of the 17th.

With the pressure high over the plains States and the Mississippi Valley and on the Pacific coast and relatively low over the intervening region, conditions were favorable during the 16th and 17th for the development of a storm over the middle Rocky Mountain region. This development took place during the 18th, and the evening of that day a storm center with barometer reading of 29.38 inches was over western Kansas. This storm advanced slowly northeastward to the Great Lakes on

the 21st, remained central in that region for several days and finally passed eastward off the Atlantic coast on the 28th. While moving from western Kansas to the Great Lakes this storm was attended by numerous thunderstorms in the middle Plains States and the Great Central Valleys and local wind storms and tornadoes within these regions. On the morning of the 20th, the day of resumption of storm warnings on the Great Lakes for the season of 1916, storm warnings were ordered for Lake Superior and the morning of the 21st for Lakes Michigan, Huron, Erie, and Ontario. The storm diminished after reaching the Upper Lake region and the storm winds were confined to Lake Superior. On the evening of the 21st, there were signs of the development of a secondary storm center over Virginia, and storm warnings were displayed on the Atlantic coast from Sandy Hook to Boston. The disturbance developed as expected, and the morning of the 22d it was central off the New Jersey coast and the evening of that date off Cape Cod. Strong, shifting winds occurred in the region where warnings were displayed. It is of interest to note that at the time the storm developed over Kansas on the 18th the synoptic cloud chart of that date showed a general flow of upper clouds toward the northeast over a widespread area extending from the Mississippi Valley westward over the Plains States and the Rocky Mountain region. The northeast movement of the upper clouds in advance of lows that form over the southwestern States is commonly observed, but it is uncommon that this movement of the upper clouds not only prevailed in advance of the storm center but as well in the region of the storm center and in its western quadrants.

Warnings of frosts were issued for southern Indiana on the 22d, for the Ohio Valley and the mountain districts of the Middle Atlantic States on the 23d, for the Ohio Valley and the Middle Atlantic States on the 24th, for the Ohio Valley on the 25th, for the region of the Great Lakes, the Ohio Valley and Tennessee on the 27th and for the Ohio Valley on the 28th.

DISTRICT WARNINGS DURING APRIL.

Chicago district.—The month was uneventful as far as the issuing of special warnings is concerned. The period was between what might be termed the cold-wave and the frost-warning season. No frost warnings were issued in the first half of the month, and those issued in the second half were few and of little importance, on account of the lateness of the season.—*H. J. Cox, Professor of Meteorology.*

Denver district.—Warnings of frost or freezing temperature were issued for some part of the district on 19 days during the month. The large number of warnings issued was due to the prevalence of threatening pressure distribution and the fact that the development of fruit and vegetation was unseasonably advanced in parts of the district. The month opened with a disturbance over southern Texas and another forming over southern Nevada. Frost warnings were issued for eastern New Mexico on the morning of the 1st. A heavy frost occurred at Roswell the following morning, with minimum temperature at the freezing point in eastern New Mexico. On the 2d warnings of frost or freezing temperature were issued for northwestern Utah. Freezing temperatures occurred the following morning in the extreme northwest portion of Utah only, as the high pressure moved well to the northward before crossing the Rocky Mountains. The morning weather map of the 3d showed increasing pressure on the eastern slope in Wyoming and freezing temperature warnings were issued for eastern Colorado. They were fully verified. Warnings of freezing temperature were again issued for eastern Colorado on the morning of the 4th and also for northern New Mexico, and frost warnings for portions of Arizona and Utah. Freezing temperatures occurred in eastern Colorado and a portion of New Mexico; although it cleared and the temperature fell in southern Arizona and southwestern Utah, frosts did not follow in these sections. On the 5th, 6th and 7th frost or freezing temperature warnings were issued for a large part of the district, as the southwestern disturbance was steadily moving southeastward and a ridge of high pressure was developing over the northern parts of the Rocky Mountain and Plateau regions. These warnings were verified over a large portion of the area for which issued, and by the morning of the 7th freezing temperature, with local frosts, had spread over the entire district, excepting the southern portions of Arizona and New Mexico, and on the 8th killing frosts extended as far southward in New Mexico as Roswell. On the 9th the pressure decreased rapidly throughout the district and temperatures were well above the normal on the 10th. Another disturbance developed over Nevada on the 10th and 11th, attended by abnormally high temperature. It moved rapidly eastward to the Plains States and was followed by an anticyclonic area of considerable intensity from the Pacific. Warnings of frost or freezing temperatures were issued on the 12th for Colorado and Utah. They were verified except in southern and western Colorado and southeastern Utah, where a disturbance that developed over northeastern Arizona caused overcast skies and rain. From the 11th to the 19th temperatures were generally above the freezing point in this district. On the 19th, however, an anticyclonic area moved eastward across the North Pacific States in the wake of a disturbance that had formed in the middle Rocky Mountain region and moved eastward to Iowa. Warnings of frost or freezing temperature issued on the 19th for Utah, Colorado, and eastern New Mexico were verified except in southeast New Mexico. The frost or freezing temperature warnings issued on the 20th were only partially verified owing to falling pressure. Another anticyclonic area appeared on the North Pacific coast on the 22d and frost warnings were issued for Utah and western Colorado, but the high moved northward to Montana and, although clear skies prevailed, temperatures were not low enough for frost to form. High pressure overspread the Plains States on the 24th, and frost or freezing temperature warnings were issued for the easternmost portions of the district on the 24th and 25th. These warnings were verified in portions of eastern Colorado on the morning of the 27th only. An area of low pressure was central on the morning of the 29th in northern New Mexico, with an anticyclonic area spreading rapidly eastward over the northern plateau. Frost warnings for Colorado and Utah were distributed and special warnings were issued for the fruit districts in Colorado on the western slope. Frost or freezing temperature warnings were also issued on the 30th for Colorado, including the fruit districts, Utah and eastern New Mexico. These warnings were fully verified in the greater part of the area, a sharp fall in temperature being general. The minimum temperatures in the fruit district on the western slope were well below the freezing point, temperatures as low as 22 degrees being registered. Smudging was resorted to quite extensively and but little damage occurred except where the orchards were not protected by smudging.—*Frederick W. Brist, Assistant Forecaster.*

New Orleans District.—On the 1st storm warnings were ordered for the Galveston section of the Texas coast and for the Louisiana coast as follows:

Hoist southeast storm warnings 8.40 a. m., Velasco, Tex., to Salmen (Slidell), La. Disturbance centered over southwest Texas will move eastward and cause moderate to strong southerly winds on the Louisiana coast and southerly to westerly winds on the Texas coast to-day and to-night.

The storm showed considerable intensity over Texas, where it caused a wind velocity of 42 miles from the southeast at Galveston, but it moved eastward less rapidly than was anticipated, diminished in intensity, and did not give a storm velocity at New Orleans.

Frost warnings were issued on the 1st for western Texas, Oklahoma, the interior of eastern Texas, and northern Arkansas, but on account of the slow movement of the storm area from Texas the high pressure from the Plains States did not move southward and frost occurred only in western Texas and the western portion of Oklahoma. Frost warnings were repeated on the 2d for Arkansas, Oklahoma, northern Texas, and northwestern Louisiana, but the high pressure area did not move southward into the west Gulf States, partly cloudy to cloudy weather prevailed and frost occurred only in Oklahoma and the northwestern portion of Arkansas. During the night of the 6th–7th an area of low pressure moved rapidly eastward from the Rio Grande Valley and gave severe local storms in the vicinity of New Orleans between 2 a. m. and 3 a. m., ninetieth meridian time, on the 7th, but the disturbance did not give a storm wind at the Weather Bureau office. (These local storms have been made the subject of a special report.) This disturbance was attended by general rains, which had been forecast. The rapid eastward movement of this disturbance followed by an area of high pressure from the northwest gave freezing temperatures in the Texas Panhandle and northwestern Oklahoma. Frost warnings were issued on the morning of the 7th for the interior of the district with freezing weather over the Texas Panhandle and northern Oklahoma. The high pressure area from the Rocky Mountain region moved southeastward until the crest on the morning of the 8th was over Nebraska and the warnings were fully verified. Warnings of freezing weather for the northern portion of the district and frost nearly to the coast were issued on the 8th. The crest of the high pressure moved from Nebraska southward into Texas and the warnings were fully verified. Frost warnings were repeated on the 9th for the west Gulf district, except the western coast of Texas. The high pressure area moved rapidly eastward until its crest rested over the South Atlantic States on the morning of the 10th, and while frost temperatures occurred over the interior of the district no general frost was reported. A storm area centered over Kansas on the morning of the 19th with an area of high pressure moving eastward from the north Pacific region, were the occasion of frost warnings for the Texas Panhandle and northwestern Oklahoma for the 20th, and frost temperature prevailed. On the morning of the 20th frost warnings were issued for the northern portion of western Texas, Oklahoma, except the southeastern portion, and the extreme northwestern portion of eastern Texas. The high pressure area did not move southeastward with the intensity anticipated and the warning was only partly verified. An area of high pressure which was over the eastern Rocky Mountain region and the Plains States on the morning of the 26th indicated frost for the northern portion of western Texas, Oklahoma, Arkansas, and the extreme northern portion of eastern Texas. While no general frost was reported, conditions showed that the warnings was justified, except in Arkansas, where the temperatures remained too high for frost. The crest of high pressure being over South Dakota on the 27th, frost warnings were repeated for Oklahoma and northern Arkansas, and frosts occurred on the 28th. Frost warnings were issued on the 30th for the Texas Panhandle and for Oklahoma, except the southeastern portion. The temperature fell to the frost point, but general cloudiness prevailed and no frost was reported. The long-range forecasts issued from the central office are given a wide distribution and are proving very valuable to agricultural and shipping interests.—*I. M. Cline, District Forecaster.*

Portland (Oreg.) District.—April was an unusual month in this district, largely because of the abnormal tracks taken by four high-pressure areas during the middle decade. Under normal conditions this month, which covers a large part of the transition period between the wet and the dry seasons, requires more than ordinary attention on the part of the forecaster, as in many localities the diurnal range in temperature is sufficient to cause the formation of frost on clear nights under almost any type of pressure distribution. Highs at the beginning and near the end of the month pursued their usual path from the California coast north to western Washington, and thence east across the Rocky Mountains, but those during the middle decade only went as far north as Oregon, when they advanced either eastward or northeastward, with the result that unsettled conditions prevailed a good portion of the time in the northwestern portion of this district in consequence of the proximity of lows over the Alaskan bight of the Pacific Ocean. Seven frost warnings for the entire district and 9 for local sections were issued, of which number 3 for general frosts were fully verified and 4 were partly verified. Of those partly verified, temperatures sufficiently low for the formation of frost occurred in praccally every instance, but no frost formed in some of the localities because of cloudiness. In the case of the 9 forecasts of frosts for local areas, 5 were fully verified, 1 was a failure, and 4 were partly verified. The failures were due to cloudiness which either prevailed all night when it was expected to clear up or it clouded up in the early morning after having been previously clear. No frosts occurred without warnings, and they were of value only in places where protective measures are taken. Not so much protective work is being done as formerly on account of the expense, as well as owing to a difference of opinion existing among horticulturists as to the effectiveness of orchard-heating methods now in general use.

One storm warning was issued to stations at the mouth of the Columbia River only, which was fully verified. Small-craft warnings were issued on 4 occasions for exposed localities in the district, but it is not known whether they were verified or not. No maximum wind velocities were reported by stations at or in the neighborhood of places where the small-craft warnings were displayed. During the night of the 16th–17th and the afternoon of the 21st, velocities slightly exceeding those necessary to verify a warning were reported at Seattle, Wash., but it is believed they were in the nature of squalls and of short duration. No warnings were displayed at the time of their occurrence. The wind also attained a maximum velocity of 64 miles per hour from the southeast at North Head during the evening of the 26th, without warnings being displayed. This was a sudden squall and lasted only a few minutes.

Four "sets" of warnings were issued for cold, wet, and windy weather for the benefit of the live stock industry. The first was on the 3d, followed by another on the 4th,

and the final one was sent on the 5th. These warnings announce (1) when the bad spell of weather will begin; (2) any changes to better or worse that are anticipated during its prevalence; and (3) when the bad spell will break and be followed by fair and warmer weather. The second "set" of warnings for the live stock people was sent on the 10th–11th and 14th, the third on the 17th–19th and 21st, and the last on the 26th and 29th. They were all fully verified and were greatly appreciated by the stock men. The Prosser State Bank of Washington wrote on April 29, 1916, as follows:

As far as I am advised, the shearing season is about closed in this vicinity. Your weather reports have assisted us very much in the past, but I do not believe they would be of any particular value now, unless, of course, something very severe should appear on your chart.

—*E. A. Beals, District Forecaster.*

San Francisco District.—There were no forecasts or warnings of marked importance issued during the month, except the "fire-weather" forecast issued to the district forester on the 29th. The forecasts of weather were generally satisfactory, except the light rain in northern California on the 11th was predicted for only the extreme north with doubtful period, and indefinite forecast for showers for the district on the 17th was a failure except in the extreme northwest and in the mountains from which no regular reports are received. The temperature forecasts were in general satisfactory, although the rapid shifting of the disturbances caused some failures. The cooler weather in Nevada on the night of the 17th–18th and in the southern portion on the 29th were not predicted.

The first warning of warm weather with north wind and conditions favorable for forest fires was issued to the district forester on the 29th and was timely, as several small fires were reported during the day of the 30th in the forests —*G. H. Willson, District Forecaster.*

SECTION IV.—RIVERS AND FLOODS.

RIVERS AND FLOODS, APRIL, 1916.

By Alfred J. Henry, Professor in Charge River and Flood Division.

[Dated: Weather Bureau, June 1, 1916.]

FLOOD IN THE MISSISSIPPI, ST. PAUL TO HANNIBAL.

The snow cover in northern Minnesota and northern Wisconsin began to melt during the closing days of March. The breaking up of the ice in conjunction with the run-off from snow, which seems to have continued during the first few days of April, caused a moderate flood wave to pass down the Mississippi during the first part of the month. The crest stages of this initial flood occurred about as follows: St. Paul, 6th; La Crosse, 10th; Dubuque, 14th; Davenport, 18th; Hannibal, 23d. A slight swell crested at St. Louis on the 22d, but the main flood wave apparently flattened out between Hannibal and St. Louis.

No sooner had this flood crest passed than a period of practically 84 hours' continuous rain set in over the middle and upper portions of the main stream—see path of Low No. xii, Chart III (xliv–48). The rain was not uniformly heavy throughout the entire period, but the fall in Minnesota and Wisconsin on the 20th–21st caused flood stages in the rivers of those States, and these floods, coming at a time when the trunk stream was already at a high stage, precipitated a second flood in the Mississippi between La Crosse and Hannibal. The movement of this flood downstream was about as follows: St. Paul, April 28; La Crosse, April 29; Dubuque, May 4; Davenport, May 7; Hannibal, May 16; St. Louis, May 20. It should be remarked that at St. Louis the flood stage was not reached. While the history of this second flood belongs in the record for May, it is convenient to consider both floods at the same time.

The principal damage caused by the flood waters was in the overflow of agricultural lands, the flooding of cellars and factories close to the stream, and the destruction of some hay that had not been removed from the bottom lands. The overflow of a large acreage of agricultural lands was accomplished mainly through overtopping and giving way of levees at various points along the river, especially in the neighborhood of Winona, Minn., and on the Illinois side of the Mississippi at various points between Rock Island and Quincy, Ill. It is yet too soon to fully measure the seriousness of the overflow, since there is a possibility of at least some of the overflowed land being planted to crops during the present season. A rough estimate of the amount of land overflowed is 70,000 acres.

The property loss due to these floods was minimized to a great extent by the warnings of their approach, which were distributed well in advance.

Statistical data of the floods in the upper Mississippi and tributaries appear in Table 1. The lower river, as may be seen from the hydrograph for Vicksburg, Chart I, rose continuously until the 26th, then began to fall. It is important to note that although the river in the stretch between Dubuque, Iowa, and Hannibal, Mo., was in flood continuously for almost half the month, the flood stage at St. Louis, Mo., was not reached. That fact was probably due to the overflow at various points in Illinois, and the channel capacity of the stream between Hannibal and St. Louis.

Red River of the North.—Owing to causes set forth in connection with the first Mississippi flood, the ice in the Red River of the North broke up and went out during the early part of the month.

The following is abstracted from a report on this flood by Observer M. R. Hovde, Devils Lake, N. Dak., in charge of the warning service on the Red River of the North:

> During the closing days of March, 1916, the river began to rise rapidly in its upper reaches (southern portion), due to the melting of a moderately deep snow layer. At this time and during the fore part of April, the main stream in its lower course (northern portion of the valley) was still icebound and the adjacent districts covered with snow to a depth of 1 or 2 feet.
>
> The ice broke up and went out on high stages substantially as forecast on an average of three days in advance. In point of magnitude the flood wave at Moorhead, Minn., was the greatest since 1902, the river cresting 4.2 feet above the flood stage. The valley surface, being simply a great, broad plain, was not damaged by the flood waters. Although the spring wheat seeding had not started, its delay by the surplus flood waters may result in decreased acreage on the farms along the river. The chief injury was to low-lying property in Fargo, Grand Forks, and Moorhead. The total damage in the valley was approximately $50,000.

Hudson River.—Flood stages were reached at Albany and Troy, N. Y., as shown in Table 5. The breaking up of the ice in the stream was not attended by serious results.

Connecticut River.—Flood stages were reached in the Connecticut twice during the month, first, on the 2d and 3d, and, second, on the 24th–25th. The first flood was due to the breaking up of the ice in conjunction with the run-off from snow. The continued melting of snow caused the river to remain at a high stage, and moderate rains on the 22d–23d caused the river to reach flood stage the second time. The damages were nominal. Statistical data are given in Table 7.

Trinity River of Texas.—Heavy rains on the 1st and 2d over the upper Trinity watershed—see path of Low No. i, Chart III—caused a sharp flood at Dallas and points above and a long-drawn out flood in the lower reaches, where the stream did not return within its banks until the middle of May (Table 3).

Brazos River of Texas.—This river was in flood locally at Waco and a short distance below from the 1st to the 3d. The damage was mainly to crops on the land that was overflowed and to bank cutting in places (Table 3).

Red River of Louisiana.—The rainstorm that caused floods in the Trinity and Brazos Rivers was also effective in producing a moderate flood in the Red and Sulphur Rivers during the early days of the month. The damage was confined mostly to the lowlands of the Red River in Arkansas, where some agricultural land was overflowed.

Rivers of Arkansas.—The same storm as above mentioned was also the cause of moderate floods in the rivers of Arkansas. Other floods occurred as shown in Table 1, due to rainstorms over the State.

Rivers of North Carolina.—Moderate rains on the 7th and 8th produced a brief flood in the Cape Fear and Neuse Rivers. No damage.

Rivers of Colorado.—Owing to the great snow cover, particularly over the higher altitudes of the western slope of the Rocky Mountains, some fear of a destructive flood in the lower Colorado had been expressed. Owing to alternating periods of warm and cold weather, the run-off from snow was not extraordinarily heavy or sustained and the month closed without the occurrence of damaging floods.

Prope.ty loss by floods.

Trinity River of Texas	$288,382
Brazos River of Texas	124,750
Ohio and Mississippi (Cairo district)	1,750
Lower Mississippi Valley (New Orleans district) January to April, inclusive:	
Buildings	31,500
Roads and bridges	16,500
Prospective crops (22,600 acres)	169,400
Crops, not housed	8,750
Live stock and other movable property	28,500
Suspension of business, including wages of employees	105,500
Loss sustained by railroads in Mississippi Valley during February and March, 1916, not previously reported	190,766
Red River (Shreveport district):	
Levees	10,000
Prospective crops (10,000 acres)	30,000
Movable property	1,500
Suspension of business	10,000
Saginaw River (March and early April):	
Tangible property	135,500
Crops not housed	500
Live stock, farm buildings	20,000
Suspension of business	27,500
Red River of the North (Devils Lake district)	50,000
Hudson River (Albany district):	
Tangible property, bridges, highways, etc	2,000
Suspension of business	1,500
Total	1,254,298

Saved by warnings.

New Orleans, La., district	$512,000
Shreveport, La., district	30,000
Saginaw, Mich., district	126,000
Albany, N. Y., district	1,000
Total	669,000

TABLE 1.—*Floods in the Mississippi River and tributaries, except the Ohio River, during April, 1916.*

River.	Station.	Flood stage.	Above flood stage.		Crest—	
			From—	To—	Stage.	Date.
		Feet.			Feet.	
Mississippi	Fort Ripley, Minn	10.0	6	9	11.4	6
Do	St. Paul, Minn	14.0	1	15	16.6	6,9
Do	do	14.0	23	(1)	15.1	28
Do	La Crosse, Wis	12.0	6	(1)	13.6	28,29
Do	Reeds Landing, Minn	12.0			11.9	26
Do	Dubuque, Iowa	18.0	13	15	18.1	14
Do	do	18.0	30	(1)	18.4	30
Do	Prairie du Chien, Wis	18.0			17.9	30
Do	Clinton, Iowa	16.0	15	19	16.4	17
Do	do	16.0	30	(1)	16.0	30
Do	Davenport, Iowa	15.0			14.5	17
Do	Le Claire, Iowa	10.0	14	(1)	11.0	17
Do	Muscatine, Iowa	16.0	17	20	16.3	18,19
Do	Keokuk, Iowa	14.0	1	4	16.0	1
Do	do	14.0	17	(1)	14.9	20
Do	Warsaw, Ill	17.0	1	4	18.6	1
Do	do	17.0	18	(1)	17.5	20
Do	Hannibal, Mo	13.0	1	10	18.3	1
Do	do	13.0	14	(1)	16.2	22,23
Do	Louisiana, Mo	12.0	1	9	16.3	1
Do	do	12.0	17	(1)	14.2	23
Do	Quincy, Ill	14.0	1	7	17.8	1
Do	do	14.0	16	(1)	16.0	21,22
Do	Grafton, Ill	18.0	1	10	20.0	4,5
Do	do	18.0	22	26	18.3	23-25
Do	St. Louis, Mo	30.0			26.3	2
Do	New Madrid, Mo	34.0	7	13	34.9	10
Do	Memphis, Tenn	35.0			34.1	13-15
Do	Helena, Ark	42.0	13	19	42.7	16,17
Do	Arkansas City, Ark	42.0	9	(1)	47.0	20-22
Do	Vicksburg, Miss	45.0	22	28	45.2	23-26
Do	Natchez, Miss	46.0			44.9	27-30
Do	New Orleans, La	18.0			16.7	29
St. Croix	Stillwater, Minn	11.3	1	(1)	15.8	25
Wisconsin	Tomahawk, Wis	14.0	22	23	15.0	22
Do	Merrill, Wis	10.5	21	24	12.6	22
Do	Wausau, Wis	10.0	22	23	11.0	22,23
Do	Knowlton, Wis	12.0	1	4	16.0	1
Do	do	12.0	21	25	17.7	23
Do	Grand Rapids, Wis	12.0	24	24	12.0	24
Do	Portage, Wis	11.0	26	28	11.6	27
Illinois	La Salle, Ill	18.0	1	22	22.3	1,2
Do	Peoria, Ill	16.0	1	16	18.4	4-6
Do	Beardstown, Ill	12.0	1	(1)	14.9	9,10
Arkansas	Dardanelle, Ark	20.0			19.7	4
Red	Fulton, Ark	28.0	7	11	29.5	9
Atchafalaya	Melville, La	37.0	1	1	37.1	1

[1] At or above flood stage at end of month.

TABLE 2.—*Floods in the Ohio River and tributaries during April, 1916.*

River.	Station.	Flood stage.	Above flood stage.		Crest—	
			From—	To—	Stage.	Date.
		Feet.			Feet.	
Ohio	Marietta, Ohio	33.0			32.5	1
Do	Parkersburg, W. Va	36.0			35.4	1
Do	Point Pleasant, W. Va	40.0	1	1	41.9	1
Do	Catlettsburg, Ky	50.0			49.3	1
Do	Portsmouth, Ohio	50.0	1	2	52.2	1
Do	Maysville, Ky	50.0	1	1	51.3	1
Do	Cincinnati, Ohio	50.0	1	3	53.5	1
Do	Fernbank (Dam 37), Ohio	50.0			49.0	1
Do	Madison, Ind	46.0			44.5	2
Do	Louisville, Ky	28.0			27.3	3
Do	Cloverport, Ky	40.0	1	6	43.3	4
Do	Evansville, Ind	35.0	1	10	39.8	5
Do	Henderson, Ky	33.0	2	10	37.8	6
Do	Mount Vernon, Ind	35.0	3	10	38.4	6,7
Do	Shawneetown, Ill	35.0	3	11	38.4	7
Do	Cairo, Ill	45.0			44.6	9
Allegheny	Olean, N. Y	12.0	1	2	13.5	1
Do	Warren, Pa	12.0	1	2	13.1	1
Do	Franklin, Pa	15.0	1	1	15.2	1

TABLE 3.—*Floods in Texas and New Mexico during April, 1916.*

River.	Station.	Flood stage.	Above flood stage.		Crest—	
			From—	To—	Stage.	Date.
		Feet.			Feet.	
Sulphur	Finley, Tex	24.0	6	10	25.0	7,8
Trinity	Fort Worth, Tex	20.0	1	8	29.6	2
Do	Dallas, Tex	25.0	2	12	39.8	3
Do	do	25.0	16	18	30.5	17
Do	Bridgeport, Tex	20.0	2	5	22.6	2
Do	Trinidad, Tex	28.0	6	23	40.5	9
Do	Long Lake, Tex	40.0	12	20	43.9	14
Do	Liberty, Tex	25.0	24	(1)	26.1	30
Brazos	Waco, Tex	22.0	2	3	33.8	2
Rio Grande	San Marcial, N. Mex	11.0	1	(1)	14.2	30

[1] At or above flood stage at end of month.

TABLE 4.—*Floods in the Great Lakes Drainage Basin, April, 1916.*

River.	Station.	Flood stage.	Above flood stage.		Crest—	
			From—	To—	Stage.	Date.
		Feet.			Feet.	
Maumee	Fort Wayne, Ind	15.0	1	1	15.7	1
Saginaw	Saginaw, Mich	19.1	1	8	24.2	1
Cass	Vassar, Mich	14.0	1	2	14.7	1
Tittabawassee	Midland, Mich	12.0	1	4	18.2	1
Chippewa	Mt. Pleasant, Mich	11.0	1	2	12.0	1
Pine	Alma, Mich	7.0	1	2	7.5	1
Grand	East Lansing, Mich	7.5			7.4	1,2
Do	Grand Rapids, Mich	11.0	1	4	14.8	1

TABLE 5.—*Floods in the Susquehanna River and tributaries during April, 1916.*

River.	Station.	Flood stage.	Above flood stage.		Crest—	
			From—	To—	Stage	Date.
		Feet.			Feet.	
Susquehanna	Oneonta, N. Y	10.0	1	15	16.7	2
Do	Bainbridge, N. Y	11.0	1	4	16.9	3
Do	Binghamton, N. Y	14.0	1	3	16.5	2
Do	Towanda, Pa	16.0	1	3	18.5	1
Do	Wilkes-Barre, Pa	20.0	1	4	26.7	2
Do	Harrisburg, Pa	17.0	1	2	17.2	1
Chenango	Sherburne, N. Y	8.0	1	3	9.0	2
Unadilla	New Berlin, N. Y	8.0	1	4	11.9	2

Table 6.—*Floods in the Hudson River and tributaries, April, 1916.*

River.	Station.	Flood stage.	Above flood stage.		Crest—	
			From—	To—	Stage.	Date.
		Feet.			*Feet.*	
Hudson	Troy, N.Y.	14.5	1	3	19.3	2
Do	Albany, N.Y.	12.0	1	3	15.8	2
Mohawk	Utica, N.Y.	11.0	....	....	10.8	2
Do	Schenectady, N.Y.	15.0	1	2	19.8	2

Table 7.—*Floods in various rivers during April, 1916.*

River.	Station.	Flood stage.	Above flood stage.		Crest—	
			From—	To—	Stage.	Date.
		Feet.			*Feet.*	
Red River of the North.	Moorhead, Minn	26.0	2	11	30.2	6
Delaware (West Branch).	Hale Eddy, N. Y	12.0	2	2	12.6	2
Delaware (East Branch).	Fishs Eddy, N. Y	10.0	2	2	11.8	2
White	White River Junction, Vt.	15.0	2	2	16.4	2
Connecticut	do	13.0	1	5	16.8	2
Do	do	13.0	23	27	14.7	24
Do	Holyoke, Mass	9.0	....	....	8.9	3
Do	Hartford, Conn	16.0	1	7	20.8	3
Do	do	16.0	26	26	16.3	26
Penobscot	West Enfield, Me	12.0	....	....	11.9	5
Neuse	Neuse, N. C	12.0	8	10	13.5	10
Do	Smithfield, N. C	13.0	9	9	13.1	9
Cape Fear	Elizabethtown, N. C	20.0	10	11	22.9	10
West Pearl	Pearl River, La	13.0	1	3	14.0	1
Gunnison (North Fork).	Paonia, Colo	8.0	28	29	8.3	29
Kings	Piedra, Cal	12.0	....	....	11.9	28, 29

Hydrographs for typical points on several principal rivers are shown on Chart I. The stations selected for charting are Keokuk, St. Louis, Memphis, Vicksburg, and New Orleans, on the Mississippi; Cincinnati and Cairo, on the Ohio; Nashville, on the Cumberland; Johnsonville, on the Tennessee; Kansas City, on the Missouri; Little Rock, on the Arkansas; and Shreveport, on the Red.

DATES OF OPENING OF NAVIGATION THROUGH LAKE PEPIN.

Dates of opening of the Mississippi River (through Lake Pepin), as reported to the United States Engineers, St. Paul, Minn., by owners of the ferryboats, at Lake City, Minn., for the years 1861 to 1916, inclusive. The dates are when Lake Pepin was sufficiently clear of ice not to impede or endanger boats passing through.

Year.	Dates.	Year.	Dates.	Year.	Dates.
1861	Apr. 7	1880	Apr. 10	1899	Apr. 20
1862	Apr. 8	1881	Apr. 13	1900	Apr. 7
1863	Apr. 5	1882	Apr. 6	1901	Apr. 6
1864	Apr. 14	1883	Apr. 15	1902	Apr. 8
1865	Apr. 15	1884	Apr. 12	1903	Apr. 4
1866	Apr. 19	1885	Apr. 20	1904	Apr. 22
1867	Apr. 19	1886	Apr. 15	1905	Apr. 10
1868	Apr. 4	1887	Apr. 15	1906	Apr. 16
1869	Apr. 20	1888	Apr. 13	1907	Apr. 4
1870	Apr. 15	1889	Apr. 12	1908	Apr. 5
1871	Apr. 17	1890	Apr. 14	1909	Apr. 12
1872	Apr. 25	1891	Apr. 16	1910	Mar. 24
1873	Apr. 17	1892	Apr. 3	1911	Mar. 28
1874	Apr. 22	1893	Apr. 12	1912	Apr. 11
1875	Apr. 20	1894	Apr.[1] 3	1913	Apr. 14
1876	Apr. 22	1895	Apr. 15	1914	Apr. 14
1877	Apr. 17	1896	Apr. 17	1915	Apr. 13
1878	Mar. 9	1897	Apr.* 6	1916	Apr. 10
1879	Apr. 4	1898	Apr. 1	Average date	Apr. 11

[1] Reported as Mar. 3, but evidently an error as to month, as the river was not open at St. Paul until Mar. 8, and at Red Wing until Mar. 21.

[J. N. R.]

SNOW SURVEYS IN CITY CREEK CANYON, UTAH, 1914, 1915, AND 1916.

By Alfred H. Thiessen, Meteorologist.

[Dated: Weather Bureau, Salt Lake City, Apr. 12, 1916.]

Snow surveys were made in City Creek Canyon by the Weather Bureau office at Salt Lake City, Utah, in March of 1914, 1915, and 1916. The accompanying map, figure 1, shows Salt Lake City with the creeks which furnish the city water. These creeks rise in the Wasatch Mountains east of the city, flow in a general westerly direction, and empty into Jordan River.

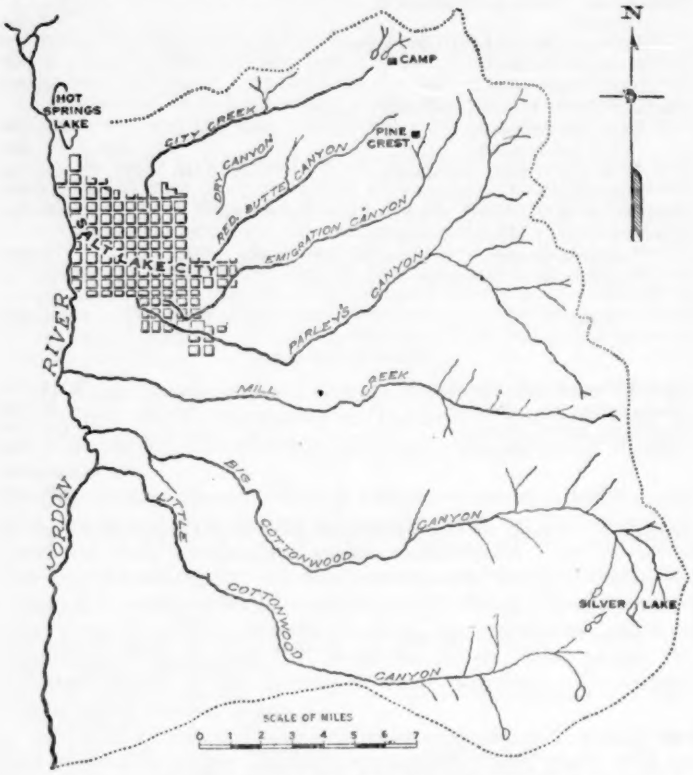

Fig. 1.—Salt Lake City, Utah, water supply is obtained from City Creek, Parleys, Emigration, and Big Cottonwood Canyons.

[Jordon River should be Jordan River.]

Salt Lake City has a right to all the water in City Creek, to 35 per cent of Big Cottonwood, to 85 per cent of Parleys, and to a small amount of Emigration canyons. It has been necessary in the past for the waterworks department to issue proclamations in the summer to the residents advising economy in the use of water, and at certain times to restrict its use for lawns to certain hours of the day or night. Under these conditions, it can be imagined how necessary it is for the waterworks department and the city engineer to know something about the available supply. The city engineer's office undertook surveying the snow in Big Cottonwood; no surveys have been made in Parleys, as it was thought that the measurements obtained in Big Cottonwood and City creeks would furnish a basis upon which the amount of water available in Parleys could be estimated.

All surveys in City Creek Canyon were made in substantially the same manner. The instrumental equipment consisted of an alpenstock graduated in inches and a Marvin snow-density tube with a balance. The region was carefully mapped, and the observations were entered in a notebook in regular sequence and also noted on a small map at the place of observation. By this method a comparison of the snow layers at the same places in different years could be made.

The method of procedure was to make many alpenstock measurements of depth at any point. By so doing a spot could be selected which would represent the average depth of the snow at the immediate place where the the surveyors were working, and then a density measurement would be made at that spot. If only one depth measurement were taken, immediately followed by a density measurement, then a hole or a hummock might have been inadvertently selected to the detriment of accuracy.

The surveyor also made notes regarding the condition of the snow, whether soft or frozen, drifted or level, the condition of the ground, whether dry or wet, frozen or soft, and any other data as to temperature, elevation, etc., that seemed needful.

The question of headquarters from which to work is of considerable importance in City Creek, which is long and narrow and impossible to work from the lower end.

As there was a summer hotel at the head of Emigration Canyon, it was thought best in March, 1914, to establish headquarters there, thinking that the surveyors could cross the divide, make the measurements, and return at night, since most of the snow lies in the upper half of the canyon. This plan was found to be practicable, but it entailed very hard work, owing to the steepness of the ascent of the divide which separated the two canyons.

In March of 1915 and 1916 surveys were again made in City Creek, but on both these occasions a camp was erected at the head of the canyon, as indicated on the map. It was necessary to drag all the supplies (instrumental equipment, food, and camp material) on improvised toboggans to the camp site. The work under this plan advanced more rapidly than in 1914, but this had also a great disadvantage in that the surveyors would be worn out by the time camp was made. The return journey in 1916, after the survey was finished, was very difficult, as the snow became very soft, and it was necessary to pack all the supplies to the nearest road.

TABLE 1.—*Comparative data of snow surveys in City Creek Canyon, Salt Lake City, Utah.*

Subarea.	Year.	Snow depth.	Water equivalent.	Per cent of water.
		Inches.	*Inches.*	
A	1914	59	19.8	34
A	1915	41	13.2	32
A	1916	60	21.4	36
B	1914	57	18.6	33
B	1915	48	14.6	30
B	1916	66	21.3	32
C	1914	64	22.6	35
C	1915	47	14.4	31
C	1916	62	21.4	35
D	1915	44	13.9	32
D	1916	57	20.5	36
E	1915	49	14.5	30
E	1916	71	23.2	33
F	1914	57	19.2	34
F	1915	45	13.9	31
F	1916	67	21.3	32
G	1914	60	20.5	34
G	1915	44	14.0	32
G	1916	62	20.9	34
H	1914	65	23.6	36
H	1915	43	14.0	33
H	1916	69	22.7	33
Whole	1914	59.9	20.4	34
Do	1915	45.9	14.2	31
Do	1916	63.2	21.3	34

1914 run-off = 31.88 cubic feet per second.
1915 run-off = 17.29 cubic feet per second.
1916 run-off = 29.6 cubic feet per second (estimated).

Table 1 shows the results of the three years of survey. A study was made of the variation of the snow supply in the smaller forks and draws as well as of the canyon as a whole. All the forks and draws where measurements were made in 1914, 1915, and 1916 were lettered, as they do not seem to have been named. The results have been tabulated, and data are given in the table, showing the average snow depth, water equivalent, and per cent of water for each lettered fork for each of the three years. At the end of the table data for the canyon, taken as a whole, are given, showing in addition the actual run-off for the period April 1 to August 31 for the years 1914 and 1915. In almost every case the smaller areas show the same variation in snow depth and water equivalent, as does the whole area. The amount of snow found this year did not vary much from that found in 1914 in regard to the three factors—snow depth, water equivalent, and per cent of water.

The amount of run-off expected from April 1 to August 31, 1916, figured on the run-off of 1914, would be 33.29 cubic feet per second; and on the run-off of 1915, it would be 25.93 cubic feet per second. The average of these two estimates would be 29.6 cubic feet per second.

The rainfall during the summer of 1915 was very small, which accounts for the comparatively small run-off during that year. If the rainfall during this coming summer is near the average, the run-off will be about the same as that of 1914, and it may be more, as the ground is now thoroughly soaked, and the run-off from the watershed area will in consequence be increased.

This is the first spring that the Weather Bureau has given the city a definite estimate of its probable water supply from City Creek. Now that the survey is made and the probable run-off based on that survey is calculated, the question as to how much water the city will get is by no means accurately settled. Early warm weather will cause rapid melting and a larger spring run-off than the city can use, and hence some water always goes to waste in the spring. Heavy summer rains will increase the run-off, while light summer rains will decrease the amount. But disregarding these disturbing factors, the city is immeasurably better prepared to administer its water supply judiciously than if the information supplied by the survey were lacking.

It should be said that at present no storage dams exist in City Creek Canyon.

MEAN LAKE LEVELS DURING APRIL, 1916.

By UNITED STATES LAKE SURVEY.

[Dated: Detroit, Mich., May 5, 1916.]

The following data are reported in the Notice to Mariners of the above date:

Data.	Lakes.			
	Superior.	Michigan and Huron.	Erie.	Ontario.
Mean level during April, 1916:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	602.38	579.92	572.42	246.40
Above or below—				
Mean stage of March, 1916	+0.21	+0.44	+0.58	+0.94
Mean stage of April, 1915	+1.06	+0.42	+0.97	+1.36
Average stage for April, last 10 years.	+0.84	−0.34	+0.04	+0.03
Highest recorded April stage	−0.31	−3.31	−1.76	−2.03
Lowest recorded April stage	+1.84	+0.70	+1.16	+1.56
Average relation of the April level to:				
March level	0.0	+0.2	+0.6	+0.5
May level	−0.3	−0.3	−0.3	−0.4

SECTION V.—SEISMOLOGY.

SEISMOLOGICAL REPORTS FOR APRIL, 1916.

W. J. HUMPHREYS, Professor in charge of Seismological Investigations.

[Dated: Weather Bureau, Washington, D. C., June 2, 1916.]

TABLE 1.—*Noninstrumental earthquake reports, April, 1916.*

Day.	Approximate time, Greenwich Civil.	Station.	Approximate latitude.	Approximate longitude.	Intensity Rossi-Forel.	Number of shocks.	Duration.	Sounds.	Remarks.	Observer.
		CALIFORNIA.								
1916.	*H. m.*		° ′	° ′			*M. s.*			
Apr13	4 23	Lone Pine	36 37	118 01	4	3	10	Rumbling	Doors rattled	G. F. Marsh.
		IDAHO.								
13	2 30	Pyle Creek (near Garden Valley).	44 07	115 56			1 0		Shook house	P. V. Smith.
14	3 55	Pyle Creek (near Garden Valley).	44 07	115 56			5		Shook house	P. V. Smith.
14	7 20	Pyle Creek (near Garden Valley).	44 07	115 56			1 0		Shook house	P. V. Smith.
30	1 50	Elk City	45 48	115 25	2	1	1			R. E. Mases.
30	3 15	Boise	43 37	116 14	3	1	1	Faint		U. S. Weather Bureau.
		NEVADA.								
18	4 50	Francis	39 44	119 58	3	2	1			Geo. W. Barnard.
		SOUTH CAROLINA.								
16	11 56	Summerville	33 03	80 14	2	1				E. H. Gadsden.
30	6 45	Summerville	33 03	80 14	2			Rumbling		E. H. Gadsden.
		WASHINGTON.								
24	4 43	Sumner	47 12	122 13	2	1	5	Rumbling		H. E. Thompson.
		PORTO RICO.								
24	4 27	Aibonito	18 08	66 17	4-5	3		Rumbling	Doors moved	D. Jordan.
	4 27	Isabela	18 30	67 04	5	1			Walls cracked slightly	William M. Orr.
	4 27	Lares	18 33	66 55	5	1	30		Partitions creaked	Paul Vilella, jr.
	4 27	Mayaguez	18 13	67 08	5	4	20	Rattling	Various buildings cracked	C. Alemar, jr.
	4 27	San Juan	18 30	66 07	4	2	10		Timbers creaked	U. S. Weather Bureau.

TABLE 2.—*Instrumental reports, April, 1916.*

[Time used: Mean Greenwich, midnight to midnight. Nomenclature: International.]

[For significance of symbols see REVIEW for January, 1916, p. 39.]

Alaska. *Sitka. Magnetic Observatory.* U. S. Coast and Geodetic Survey. J. W. Green.

Lat. 57° 03′ 00″ N.; long., 135° 30′ 06″ W. Elevation, 15.2 meters.
Instruments: Two Bosch-Omori, 10 and 12 kg.

Instrumental constants: E: V 10, T_0 16.7; N: V 10, T_0 15.4

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 2		eL_N	8 25 20	11				
		eL_E	8 25 32	11				
		M_E	8 26 12	10	50			
		M_N	8 26 34	10		60		
		F_E	8 36 00	7				
		F_N	8 40 00	8				
18		P	3 06 13	4				
		S_E	3 10 08	10				
		S_N	3 09 58	10				
		M_E	3 10 16	10	260			
		M_N	3 11 12	10		520		
		L_N	3 12 06	12				
		M_E	3 12 12	12	190			
		M_N	3 12 36	13		110		
		C	3 24 00	7				
		F_N	4 14 00					
		F_E	4 34 00					

Alaska. *Sitka. Magnetic Observatory*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 24		eL_E	4 45 00					
		eL_N	4 47 20	18				
		M_N	5 00 50	16		50		
		F_E	5 14 00					
		F_N	5 39 00					
24		eP_E	8 16 25					
		eP_N	8 17 44					
		L_N	8 29 00	28				
		M_N	8 41 03	20		70		
		C_N	8 44 30	13				
		M_E	8 47 40	15	20			
		F_E	9 18 00					
		F_N	9 31 00					
26		eL_N	2 49 49	40				Barely perceptible on E.
		M_N	3 00 08	13		60		
		C_N	[illegible] 06 50					
		F_N	3 39 00					

TABLE 2.—*Instrumental reports, April, 1916*—Continued.

Arizona. *Tucson.* *Magnetic Observatory.* U. S. Coast and Geodetic Survey. F. P. Ulrich.

Lat. 32° 14′ 48″ N.; long., 110° 50′ 06″ W. Elevation, 769.6 meters.

Instruments: Two Bosch-Omori, 10 and 12 kg.

Instrumental constants: E: V 10, T_0 16; N: V 10, T_0 19.6

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 2		eL	8 35 00	11				
		M	8 37 00	10	10	10		
		F	8 43 00					
2		eL	18 58 42	3				
		M_E	18 59 08	10	40			
		M_N	18 59 19	5		10		
		F	19 08 00	5				
14		eP	20 35 59	4				
		L_E	20 41 35					
		L_N	20 42 05					
		M	20 42 30	5	50	40		
		C	20 46 00					
		F	20 54 00	4				
16		P_N	22 31 27	4				
		S_E	22 33 57	3				
		L	22 36 27	5				
		M	22 38 37	10	50	150		
		C	22 40 00	8				
		F_E	22 55 00	8				
		F_N	23 05 00	7				
18		P_E	4 10 07	4				N not in operation.
		S_E	4 17 03					
		M_E	4 21 10	9	10			
		M_E	4 32 25		50			
		C	4 44 00					
		F	6 56 00	7				
21		eP_E	11 54 48	5				N not in adjustment.
		L_E	12 14 18					
		M_E	12 17 15	20	20			
		C_E	12 23 00					
		F_E	12 47 00	16				
24		eL_E	4 36 05	5				
		eL_N	4 40 14	4				
		M_N	4 43 42	13		10		
		M_E	4 45 10	9	10			
		F_N	5 07 00	8				
		F_E	5 14 00	8				
24		P	8 08 52	4				
		eL_E	8 17 12	16				
		eL_N	8 17 46	34				
		M_N	8 28 01	18		90		
		M_E	8 29 39	16	60			
		C	8 36 00	13				
		F_N	9 07 00	12				
		F_E	9 22 00	10				
26		P	2 28 24	4				
		eL	2 38 59					
		M_N	2 41 55	18		40		
		M_E	2 43 03	16	60			
		F_E	3 07 00	8				
		F_N	3 10 00	9				

California. *Berkeley.* *University of California.*

Lat., 37° 52′ 16″ N.; long., 122° 15′ 37″ W. Elevation, 85.4 meters.

(*See* Bulletin of the Seismographic Stations, University of California.)

California. *Mount Hamilton.* *Lick Observatory.*

Lat., 37° 20′ 24″ N.; long., 121° 38′ 34″ W. Elevation, 1,281.7 meters.

(*See* Bulletin of the Seismographic Stations, University of California.)

California. *Point Loma.* *Raja Yoga Academy.* F. J. Dick.

Lat., 32° 43′ 03″ N.; long., 117° 15′ 10″ W. Elevation, 91.4 meters.

Instrument: Two-component, C. D. West seismoscope.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 29					*100	*100		Tremors recorded during 24 hours preceding 4 p. m.

* Amplitude on instrument.

California. *Santa Clara.* *University of Santa Clara.* J. S. Ricard, S. J.

Lat., 37° 26′ 36″ N.; long., 121° 57′ 63″ W. Elevation, 27.43 meters.

(*See* Record of the Seismographic Station, University of Santa Clara.

Colorado. *Denver.* *Sacred Heart College.* *Earthquake Station.* A. W. Forstall, S. J.

Lat., 39° 40′ 36″ N.; long., 104° 56′ 54″ W. Elevation, 1,655 meters.

Instrument: Wiechert 80 kg., astatic, horizontal pendulum.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 6	I_r	P_E	18 55 00					Second preliminaries doubtful. Visible activity preceded and followed.
		S_E	19 00 00					
		L_E	19 07 00					
		M_E	19 08 00	7–5	12.5			
		F_E	19 09 00					
13	I_u	L_N	19 45 00					Small irregular waves more prominent on N–S.
		F_N	19 50 00					
14		M_E	18 54 00	15				Long irregular waves.
		F_E	19 02 00	15				Thickening of pen-marks.
15		M_N	18 40 00	7				Much disturbed by minutes marks.
		F_N	19 30 00	5–7				
16	I_r	L_N	22 38 00	4–7		6		Preliminaries doubtful on account of minutes marks.
		M_N	22 40 00	4–7		10		
		C_N	22 41 00					
		F_N	22 43 00					
24	I_r	P	9 18 00					1st and specially 2d preliminaries doubtful.
		L	9 25 00					
		M_E	9 28 00	15	9			
		M_N	9 30 00	15		7		
		F_N	9 34 00					
		F_E	9 40 00					
26	I_r	L	2 44 00					Preliminaries not discernible.
		M_E	2 44 00	30	6.2			
		M_N	2 44 00	30		4.1		
		F_N	2 48 00					
		F_E	2 54 00					

District of Columbia. *Washington.* *U. S. Weather Bureau.*

Lat., 38° 54′ 12″ N.; long., 77° 03′ 03″ W. Elevation, 21 meters.

Instrument: Marvin (vertical pendulum), undamped. Mechanical registration.

Instrumental constants: V 110, T_0 6

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 2		e_N	8 36 30					
		S_N?	8 38 47					
		L_N	8 42 00					
		F	9 10 00					
2		e	18 56 33					
		S?	19 01 15					
		L?	19 06 30					
		F	19 20 00					
6		L	19 19 36					Beginning lost in microseisms.
		F	19 35 00					

TABLE 2.—*Instrumental reports, April, 1916*—Continued.

District of Columbia. *Washington.* *U. S. Weather Bureau.*—Contd.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 7		e_N	9 45 40					No distinct maximum.
		i	9 48 40					
		L	10 07 10					
		L	10 35 00	35				
		L	10 37 00	20				
		L	10 50 00	16				
		F	12 00 00					
11		S?	3 58 46					All phases doubtful.
		F	4 15 00					
15		E	12 51 14					
		L	14 03 20	20				
		F	14 20 00					
16		e_N	22 45 20					Phases uncertain. Lost in microseisms.
		F	23 10 00					
18	III_u	P	4 11 48				6,750	
		S	4 20 04					
		M	4 21 50		105			
		L	4 29 12	14				
		F	5 40 00					
21	III_r	P	11 49 45				4,460	
		S	11 55 58					
		L	12 04 02	16				
		L	12 20 00	24				
		F	13 20 00					
24	III_r	P	4 31 26				2,375	
		S	4 35 21					
		L	4 39 20	16				
		F	5 50 00					
24	III_r	P	8 08 13				2,590	
		S	8 12 25					
		L	8 16 30	16				
		F	10 00 00					
26	II_r	P	2 27 36				3,290	
		S	2 32 40					
		L	2 34 52	12				
		L	2 37 00	20				
		F	3 40 00					
26	II_r	P	6 31 42				3,450	
		S	6 36 56					
		L	6 42 00	16				
		F	7 10 00					
26	II_r	P?	7 21 56				3,480?	
		S	7 27 12					
		L	7 33 04	16				
		F	8 00 00					
26		e	12 50 00					Phases doubtful.
		F	13 20 00					

District of Columbia. *Washington.* *Georgetown University.*

F. L. Tondorf, S. J.

Lat., 38° 54′ 25″ N.; long., 77° 04′ 24″ W. Elevation, 42.4 meters. Subsoil: Decayed diorite.

Instruments: Wiechert 200 kg. astatic horizontal pendulums, 80 kg. vertical.

Instrumental constants:	*V*	T_0	ϵ
E	165	5.4	2.6
N	143	5.2	3.4
Z	*80*	*3.0*	*0*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 2		e_E	8 36 27					N–S scarcely discernible. Gram on Wiechert lost in microseisms. Bosch-Omori shows L at $8^h 41^m 35^s$ to $8^h 53^m 29^s$.
		P_E?	8 42 06					
		L_E	8 45 43	30				
		F	9 15 00					

District of Columbia. *Washington.* *Georgetown University*—Contd.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 7		e_E	9 33 20					No distinct main.
		e_N	9 33 54					
		L	10 22 10					
		L	10 59 30					
		F	12 plus					
11		e_N	3 53 17					All phases rather doubtful. Microseisms. Mainka shows eL_E $3^h 58^m 17^s$; eL_N $3^h 58^m 30^s$. S_N not discernible.
		e_E	3 53 25					
		S_E?	3 57 39					
		S_N						
		eL_N	3 58 39					
		eL_E	3 58 57					
		L_N	3 59 17					
		F	4 10 00					
16		e_N	22 45 09					Heavy microseisms. Phases not clear.
		e_E	22 45 27					
		S_N?	22 49 33					
		F	23 14 00					
18		iP_E	4 11 50					Wind marks. Mainka shows P at $4^h 11^m 53^s$; S at $4^h 20^m 4^s$. No distinct M on N–S component.
		iP_N	4 11 50					
		S_E	4 20 00					
		S_N	4 20 01					
		eL_N	4 28 32	9				
		eL_E	4 28 56	9				
		$M1_E$	4 34 32	8	8			
		$M2_E$	4 36 16	8	7			
		F	5 17 00					
21		e_N	11 50 26					Wiechert shows: e_E at $11^h 51^m 50^s$; e_N at $11^h 51^m 56^s$; L_E at $12^h 4^m 9^s$; L_N at $12^h 4^m 9^s$. No distinct M, and S_N doubtful.
		e_E	11 50 39					
		S_E	11 55 56					
		S_N						
		eL_E	11 57 00					
		L_N	12 02 36	15				
		L_E	12 04 03	20				
		F	13 03 00					
24		iP_N	4 31 25					No decided main. P–S on Mainka $3^m 57^s$.
		iP_E	4 31 26					
		iS_E	4 35 25					
		iS_N	4 35 28					
		eL_N	4 36 39	10				
		eL_E	4 37 00	10				
		F	5 20 00					

VERTICAL

Date.	Character.	Phase.	Time.	Period T.	A_Z		Distance.	Remarks.
		iP	*4 31 37*					No decided main.
		iS	*4 35 33*					
		eL?	*4 36 34*					
24		eP_E	8 08 11					
		iP_N	8 08 17					
		S_E	8 13 30					
		S_N	8 13 33					
		eL_E	8 16 03	20				
		eL_N	8 16 36	15				
		M_N	8 20 21	20		25		
		M_E	8 20 49	15	22			
		F	9 16 00					
26		eP_N	2 27 28					Mainka shows P at $2^h 27^m 27^s$; S at $2^h 32^m 40^s$.
		eP_E	2 27 34					
		eS_E	2 32 34					
		iS_N	2 32 37					
		eL_E	2 34 48	15				
		eL_N	2 34 51	15				
		M_N	2 39 05	18		10		
		M_E	2 40 18	20	17			
		F	3 35 00					
26		e_E	6 32 34					Microseisms. No distinct main.
		e_N	6 32 51					
		eL_E?	6 39 48					
		eL_N?	6 42 29					
		L_E	6 42 29	20				
		L_N	6 43 34	17				
		F	6 56 00					
26		e	7 24 32					Microseisms. No distinct main.
		L_E	7 33 34					
		L_N	7 34 24					
		F	8 14 00					

TABLE 2.—*Instrumental reports, April, 1916*—Continued.

Hawaii. *Honolulu. Magnetic Observatory.* U. S. Coast and Geodetic Survey. Wm. W. Merrymon.

Lat., 21° 19′ 12″ N.; long., 158° 03′ 48″ W. Elevation, 15.2 meters.

Instruments: Milne seismograph of the Seismological Committee of the British Association.

Instrumental constant.. T_0 18.9

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 2		L	8 36 54					
		M	8 37 48		*100			
		F	8 44 00					
3		eP	10 35 30					
		L	10 40 00					
		M	10 43 30		*250			
		C	10 49 42					
		F	11 08 48					
7		P	9 46 54					
		S	10 00 06					
		L	10 22 00	22.4				
		M	10 47 42		*3400			
		C	11 07 48					
		F	12 30 48					
12		e	9 34 06					
		L	9 43 36	24				
		M	9 48 36		*400			
		C	9 53 48					
		F	10 06 48					
14		L	17 49 42	22.2				P and S doubtful. Observer taking time break.
		M	17 52 42		*300			
		C	17 56 12					
		F	18 20 12					
14		eL	20 57 24	23				
		M	21 01 00		*250			
		F	21 05 36					
14		eL	21 46 18					
		M	21 57 42		*300			
		C	21 57 12					
		F	22 30 30					
15		e	12 56 48					Phases uncertain.
		eL	13 21 00					
		M	13 39 18		*450			
		C	13 57 12					
		F	15 58 18					
18		P	4 07 24					Maximum very abrupt.
		eL	4 13 42	21.0				
		M	4 16 06		*3700			
		C	4 45 54					
		F	6 08 00					
21		P	11 41 42					
		S	11 49 48					
		L	11 59 48	23				
		M	12 02 54		*8400			
		C	12 38 36					
		F	14 43 24					
24		P	4 39 30					L indeterminate.
		S	4 49 24					
		M	5 16 24		*300			
		C	5 19 36					
		F	6 20 18					
24		P	8 14 00					
		S	8 23 06					
		L	8 36 54	20.5				
		M	8 39 42		*1500			
		C	9 08 18					
		F	11 23 42					
26		P	2 33 06					
		S	2 42 36					
		L	2 55 12	23				
		M	2 59 36		*1200			
		C	3 25 06					
		F	5 09 06					
26		eP	6 46 42					
		eL	7 00 06	22				
		M	7 02 48		*200			
		C	7 10 24					
		F	8 51 12					

*Trace amplitude.

Kansas. *Lawrence. University of Kansas.* Department of Physics and Astronomy. F. E. Kester.

Lat., 38° 57′ 30″ N.; long., 95° 14′ 58″ W. Elevation, 301.1 meters.

Instrument: Wiechert.

		V	T_0	ϵ
Instrumental constants..	E	177	3.4	4.0
	N	205	3.4	3.8

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 14		P_N	20 36 20					
		P_E	20 36 25					Apparently partially due to N-S motion of pendulum.
		P_N	20 36 28			2		
		L_E	20 40 21					
		L_N	20 40 24					
		L_N	20 40 31			4		
		F	20 58 00					
16		P_N	22 31 45					
		P_N	22 32 46					
		P_E	22 32 51					
		S	22 36 24					
		L_E	22 39 21					
		L_N	22 39 23					
		M_E	22 39 43		6			
		M_N	22 40 03	4-5		3		
		F	23 11 —					
18		P	4 10 39					
		L	4 17 44	8-9				
		M_N	4 18 06			9		
		M_E	4 18 09		11			
		F	5 35 00					
24		P	4 32 49					
		L	4 37 51					
		M_E	4 43 19		4			
		M_N	4 43 22			4		
		F	5 22 —					
24		P1	8 08 23			1		
		P2	8 09 37	5-6	6	5		
		S	8 11 15					
		L	8 13 25	12-20				
		M_E	8 22 53	20	4			
		M_N	8 28 47	15		2		
		F	9 20 00					
26		P	2 27 48			1		
		S?L	2 32 53					
		L_E	2 34 41					
		L_N	2 35 01					
		M_N	2 35 10	8		2		
		M_E	2 35 11	12	5			
			2 37 00	40				
			2 40 00	30				
		F	3 14 00					

Maryland. *Cheltenham. Magnetic Observatory.* U. S. Coast and Geodetic Survey. George Hartnell.

Lat., 38° 44′ 00″ N.; long., 76° 50′ 30″ W. Elevation, 71.6 meters.

Instruments: Two Bosch-Omori, 10 and 12 kg.

		V	T_0
Instrumental constants..	E	10	31
	N	10	29

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 18		P	4 11 49	4				
		S	4 20 07	4				
		L	4 32 30	12				
		M	4 40 46	13	60	50		
		C	4 49 00					
		F	5 07 00					
21		P_E	11 48 34	8				Barely discernible on N.
		S_E	11 56 52	10				
		L_E	12 03 44	18				
		M_E	12 04 22	16	50	10		
		C_E	12 52 00	16				
		F_E	13 12 00	12				
24		P	4 31 29	3				
		S	4 35 24	8				
		M	4 35 36	8	350	200		
		L	4 38 06	21				
		M_N	4 39 36	18		80		
		M_E	4 41 50	8	40			
		C_N	4 43 00					
		C_E	4 48 00					
		F_N	5 08 00					
		F_E	5 26 00					

TABLE 2.—*Instrumental reports, April, 1916*—Continued.

Maryland. *Cheltenham. Magnetic Observatory*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Apr. 24		P	8 08 17	4				
		S_E	8 13 15	18				
		S_N	8 13 36	18				
		L_E	8 16 30	30				
		eL_N	8 18 40	22				
		M_E	8 20 09	20	930			
		M_N	8 20 58	21		2,310		
		C	8 26 00	16				
		F	9 20 00	17				
26		P_N	2 27 28	3				
		P_E	2 28 36	3				
		S	2 32 34	8				
		L_E	2 34 52	29				
		eL_N	2 35 03	24				
		M_E	2 36 48	29	3,140			
		M_N	2 40 25	18		250		
		C_E	2 42 00	16				
		C_N	2 45 00	14				
		F_N	3 14 00					
		F_E	3 32 00					
26		eP_N	6 30 55	12				
		eL_N	6 38 57	20				
		eL_E	6 41 25					
		M_E	6 44 45	17	10			
		M_N	6 45 07	17		40		
		F	7 04 00					
26		eP_E	7 28 17	8				
		L	7 33 11	16				
		M_N	7 35 25	16		10		
		M_E	7 36 56	16	30			
		F	7 54 00					

Massachusetts. *Cambridge. Harvard University Seismographic Station.* J. B. Woodworth.

Lat., 42° 22′ 36″ N.; long., 71° 06′ 59″ W. Elevation, 5.4 meters. Foundation: Glacial sand over clay.

Instruments: Two Bosch-Omori 100 kg. horizontal pendulums (mechanical registration).

		V	T_0	ε:1
Instrumental constants..	E	80	23	0
	N	50	25	4:1

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Apr. 2		*O*?	*8 24 03*				4,840?	Δ and *O* quite uncertain. Pendulum began to drift E.
		e_E	8 36 00					
		S_E?	8 38 54	7				
		eL_N	8 43 11					
		eL_E	8 43 14	15				
		L_E	9 04 10	12–15				
		F_E	9 10 24					
2		e?	19 06 07					e earlier? among irregular waves.
		L_E	19 11 15	15–20				
		L_E	19 16 12	10				
		L_N	19 16 16	10				
		F?						F uncertain.
4		e	21 22 50					In microseisms.
		L?	21 25 31	20				
		F?	21 29 43					
5		e	3 24 27					Do.
		F	3 31 51					
6		L_E	19 06 44					N record masked by microseisms.
		L	19 21 31					
		F	19 38 —					
7		*O*	*9 35 35*				10,500	
		iP_E	9 49 11					
		S_E	10 00 31					
		R	10 06 56					
		eL_E?	10 21 13					
		$LR1_E$	11 18 53	24				
		F_E	12 07 00					
11		e?	3 58 24					Short periods masked by microseisms. Not detectible on damped component.
		i	3 58 59	4				
		eL?	4 00 00	16, 14, 9, 7				
		F	4 15 25					
14		L_E	15 54 05					
		L	15 55 07	15				
		L	15 58 43	10				
		F	17 01 —					
Apr. 14		L_E?	18 28 44					Between 14^h and 20^h, nearly continuous vibrations registered on E component, with periods varying from 8 to 12 secs.
		L_E	18 32 04					
		F?	— — —					
14		L_E	20 34 56					
		L	20 43 15	9				
		L	20 48 47	8				
		L	20 54 35	12				
		L	21 09 18					
		F	21 18 00					
14		L_E	21 41 56					
		L	22 04 39	14				
		L	22 11 01	18–20				
		F	22 37 —					
15		e?	12 51 17	8				N record in microseisms.
		i	13 02 24	10				
		i	13 07 22	14				
		L_E	13 52 09	20				Changed E record between 13^h 37^m and 13^h 45^m.
		L	13 54 42	28				
		L	14 17 22	15				
		F?	14 23 51					F later? in microseisms.
16		*O*?	*22 40 07*				2,460?	
		eP_E?	22 45 10					In microseisms.
		e	22 48 12					
		S	22 49 12	6.4				
		eL_E?	22 50 14					
		L	22 51 25	12				
		L	22 55 56	9				
		F_E	23 11 00					
17		*O*	*18 29 18*				260	Not heard from.
		P_N	18 30 09					
		M	18 30 38	1				
		F	18 31 20					
18		*O*	*4 01 43*				6,700	
		iP_N	4 11 54					
		iP_E	4 11 57					
		$PR1_N$	4 14 25					
		S_N	4 20 07	6				
		S_E	4 20 10					S with A large to 4^h 21^m 55^s.
		i_{NE}	4 21 42					
		eL_E	4 31 09					
		L_N	4 34 00	11				
		L_E	4 34 32	13				
		M_E	4 35 00					E undamped.
		M_E	4 37 00					
		M_E	4 40 00					
		F	6 11 00					
18		e	22 40 08; 22 42 14	8–10				e earlier in microseisms.
21		*O*?	*11 plus*					Very distant.
		e_E	11 46 10	10				Undamped component.
		M?	11 56 51	18				Periods variable.
		M	12 04 52	20				Followed by L of variable periods up to 38^s. Changed records. Microseisms mainly on N components.
		F?	13 39 00					
22		*O*?	*20 40 00*				55?	Local shock. Record shows large amplitude on side of indicator unconfined by the suspended wheel contact with the main boom, evidently due to motion of the indicator independently of the pendulum.
		eP_N	20 40 27					
		M	20 40 34					
		F	20 40 48					
24		*O*	*4 26 26*				2,650	
		P_N	4 31 49					
		eP_E	4 31 56					
		S_N	4 36 06					
		eL_N	4 39 41	15				
		F	5 42 00					
24		*O*	*8 02 29*				3,320	
		P_N	8 08 58					
		eP_E	8 09 06					
		i_N	8 10 23					
		i_E	8 10 31					
		S_N?	8 14 03					
		S_E	8 14 38					
		eL_E	8 19 30					
		eL_N	8 20 08	20				Later 26, 20.
		M_N	8 25 52					A_N 175 micra.
		F	10 10 00					

TABLE 2.—*Instrumental reports, April, 1916*—Continued.

Massachusetts. *Cambridge. Harvard University*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 26		*O*	*2 21 19*				3,730	
		P_N	2 28 17	2				P_N strong.
		P_E	2 28 22					
		i_N	2 29 50	4				
		S_N	2 33 48	7				S in microseisms.
		S_E	2 33 56					
		iL_E	2 36 52					Undamped component.
		eL_N	2 37 40	20				
		L_N	2 40 53					No decided M_N.
		L_E	2 44 50					
		F	3 43 00					
26		*O?*	*5 55 00*				14,500	Δ from L-LR1.
		i_N	6 32 27	2.4				
		i	6 33 48	3.4				
		e_E	6 38 15					E pendulum drifts E.
		eL_E?	6 46 08	20				
		L	6 47 11					
		L_N	6 47 42	15				
		L_N	{ 7 38 06 / 7 41 46 }	20–16				L=LR1?.

Missouri. *Saint Louis. St. Louis University.* Geophysical Observatory. J. B. Goesse, S. J.

Lat., 38° 38′ 15″ N.; long., 90° 13′ 58″ W. Elevation, 160.4 meters. Foundation: 12 feet of tough clay over limestone of Mississippi system, about 300 feet thick.

Instrument: Wiechert 80 kg. astatic, horizontal pendulum.

	V	T_0	ε:1
Instrumental constants..	80	7	5:1

Date.	Character.	Phase.	Time.	Period T.	A_E	A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 18	II_u	eS	4 11 00				6,000?	
		L2	4 18 45					
		F	4 50 00					
24	II_r	eS	4 33 00				3,000?	
		L	4 38 00					
		F	4 53 00					
24	II_r	eS_N	8 09 00				3,000	
		L_N	8 14 30					
		M_N	8 18 00	12		12		
		F	8 44 00					
27	II_r	eP	2 28 34				3,100	
		S	2 33 30					
		L	2 35 18					
		F	2 59 00					

New York. *Buffalo. Canisius College.* John A. Curtin, S. J.

Lat., 42° 53′ 02″ N.; long., 78° 52′ 40″ W. Elevation, 190.5 meters.

Instrument: Wiechert 80 kg. horizontal.

	V	T_0	ε:1
Instrumental constants..	80	7	5:1

Date.	Character.	Phase.	Time.	Period T.	A_E	A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 7	III_r	eP_E	9 49 45					
		M_E	10 42 00	20	7			
		M_N	10 43 00					
		C_N	10 53 00					
		C_E	10 58 00					
		F_E	11 47 00					
17	III_r	eP_E	4 10 30					
		eP_N	4 10 35					
		S_E	4 18 30	7.5	87			S_E and S_N are of extraordinary amplitude compared with M_E and M_N.
		S_N	4 18 35	6.5		175		
		M_E	4 30 00	15	25			
		M_N	4 30 15	15		37		
		F_E	5 20 00					
		F_N	5 20 00					
24	III_r	eP_E	4 31 30					Reported from Santo Domingo, Haiti.
		iP_N	4 31 35					
		S_E	4 36 00					
		S_N	4 36 00					
		M_N	4 43 00	17		18		
		M_E	4 44 00	16	20			
		C_E	4 47 00					
		C_N	4 48 00					
		F_N	5 08 00					
		F_E	5 10 00					

New York. *Buffalo. Canisius College*—Continued.

Date.	Character.	Phase.	Time.	Period T.	A_E	A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 24	III_r	eP_E	8 08 15					
		iP_N	8 08 20					
		S_E	8 13 25					
		S_N	8 13 30					
		L_N	8 16 00					
		L_E	8 16 15					
		M_E	8 20 00	24	50			
		M_N	8 21 00	20		87		
		C_E	8 25 00					
		C_N	8 26 00					
		F_E	9 12 00					
		F_N	9 13 00					
24	II?	M_N	16 10 25			6		P and S masked by microseisms.
		M_E	16 10 40		2			
26	III_r	iP_N	2 27 15					
		eP_E	2 27 45					
		M_N	2 34 15					
		M_E	2 34 45					
		C_E	2 42 00					
		C_N	2 43 00					
		F_N	3 27 00					
		F_E	3 28 00					
26	III_r	eP_E	6 39 00					
		eP_N	6 40 15					
		M_E	6 43 15	15	4			
		S_N	6 44 15					
		C_E	6 46 00					
		M_N	6 46 10	20		12		
		C_N	6 47 00					
		F_E	6 50 00					
		F_N	6 52 00					

New York. *Fordham. Fordham University.* W. C. Repetti, S. J.

Lat., 40° 51′ 47″ N.; long., 73° 53′ 08″ W. Elevation, 23.9 meters.

Instrument: Wiechert, 80 kg.

		V	T_0	ε:1
Instrumental constants..	E	72	7.2	1.5:1
	N	72	7.2	3.8:1

Date.	Character.	Phase.	Time.	Period T.	A_E	A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 1–21								Out of service.
24		iP_N	4 27 05					E-W component not working.
		iS_N	4 31 16					
		eL_N	4 34 13	18				
		M_N	4 39 36	14		16		
		F_N	4 59 00					
24		iP_N	8 04 11	4				E-W component not working.
		$PR1_N$	8 05 18					
		iS_N	8 09 33					
		$SR1_N$	8 10 37	22		37		
		eL_N	8 13 07					
		M_N	8 18 44	16		75		
		F_N	9 00 00					
26		eP_N	2 23 28					
		eP_E	2 23 36					
		iS_N	2 31 44					
		iS_E	2 31 44					
		L_E	2 34 16					
		L_N	2 35 16					
		M_N	2 37 56	22		33		
		M_E	2 38 13	22	49			
		F_E	2 53 00					
		F_N	2 55 00					
26		L_N	6 40 17	15				
26		i_N?	7 20 17					
		L_N	7 24 53					
		F_N	7 40 00					

TABLE 2.—*Instrumental reports, April, 1916*—Continued.

New York. *Ithaca. Cornell University.* Heinrich Ries.

Lat., 42° 26′ 58″ N.; long., 76° 29′ 09″ W. Elevation, 242.6 meters.

Instruments: Two Bosch-Omori, 25 kg., horizontal pendulums (mechanical registration).

Instrumental constants.. E: V 13, T_0 22, ε 4:1; N: V 14, T_0 25, ε 4:1

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			H. m. s.	Sec.	μ	μ	Km.	
Apr. 7		eP_E?	9 48 18	4–5				Microseisms.
		eL_N	10 28 00	16–20				
		eL_E	10 37 17	20				
		F_N	10 58 00					
		F_E	11 44 00					
11		L_E	3 57 40					Microseisms.
		L_N	3 57 47	17–8				
		F_E	4 03 00					
		F_N	4 03 30					
16		e_N	22 46 51	4–9				
		F_N	22 59 00					
18		P_E	4 11 23	4				Beginning of L indistinct.
		P_N	4 11 25	3–6				
		S_N	4 19 22	10		100		
		iS_E	4 19 24	8	146			
		eL_E	4 29 15	8				
		F_E	5 14 00					
		F_N	5 18 30					
24		P_N	4 31 52					E–W record poor because of badly sooted paper.
			4 32 13	3–5				
		S_N	4 36 15	9		71		
		eL_N	4 40 02	23–12		107		
		F_N	5 15 00					
24		P_N	8 08 39	5				E–W record poor.
		$PR1_N$	8 09 49	5–8		64		
		S_N	8 14 05	5–16		107		
		eL_N	8 18 45	30				
		M_N	8 24 19	16		550		
		F_N	9 21 00					
26		P_N	2 27 55	3				
		e_E	2 29 35					
		S_E	2 33 17	8				
		L_E	2 35 20	35–14				
		L_N	2 36 06	23				
		M_N	2 42 26	18		143		
		F_E	3 08 00					
		F_N	3 28 00					
26		e_N	6 33 08	8				
		L_N	6 38 02	22				
		L_E	6 44 00	21				
		F_E	6 57 00					
		F_N	7 08 00					
28		e_N	7 23 44	9				
		L_N	7 28 20	24				
		L_E	7 34 34	21				
		M_N	7 38 11	15		21		
		F_E	7 48 00					
		F_N	8 05 00					

Panama Canal Zone. *Balboa Heights.* Isthmian Canal Commission.

Lat., 8° 57′ 39″ N.; long., 79° 33′ 29″ W. Elevation, 27.6 meters.

Instruments: Two Bosch-Omori 100 kg.

Instrumental constants.. V 10, T_0 20

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			H. m. s.	Sec.	μ	μ	Km.	
Apr. 12		P	18 45 23				684	Direction N. W.?
		L	18 46 52					
		M_E	18 47 00		50			
		M_N	18 47 07			80		
		F	18 49 56					
18		L_N	4 24 10					Distance and direction?
		L_E	4 24 14					
		M_E	4 24 26		50			
		M_N	4 24 30			300		

Panama Canal Zone. *Balboa Heights*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			H. m. s.	Sec.	μ	μ	Km.	
Apr. 24		P	4 30 00				966	Direction NW.?
		L	4 32 28					
		M_N	4 32 50			200		
		M_E	4 32 53		180			
		F	4 38 20					
24		P_E	8 02 30				764	Direction NW.? No record on N-S, pen thrown off recording drum.
		S_E	8 02 54					
		L_E	8 04 10					
		M_E	8 04 30		5600			
		F	8 36 00					
26		P	2 22 36				401	Direction NW.?
		L_N	2 23 24					
		L_E	2 23 28					
		M_E			7500+			Pen went off sheet.
		M_N				7200+		Pen went off sheet.
		F_E	2 44 00					
		F_N	2 50 04					
26		P	5 41 25				473	Direction NW.?
		L	5 42 25					
		M_N	5 42 40			80		
		M_E	5 42 57		50			
		F_E	5 45 50					
		F_N	5 46 00					
26		P	6 26 43				518	Direction NW.?
		L_E	6 27 47					
		L_N	6 27 51					
		M_E	6 28 12		350			
		M_N	6 28 25			500		
		F_E	6 40 00					
		F_N	6 40 20					
26		P	7 17 20				663	Direction NW.?
		L_N	7 18 44					
		L_E	7 18 48					
		M_N	7 19 28			1700		
		M_E	7 20 44		1600			
		F_E	7 34 10					
		F_N	7 35 00					
26		P	12 41 56				489	Direction NW.?
		L_N	12 42 56					
		L_E	12 43 00					
		M_N	12 43 35			400		
		M_E	12 43 50		300			
		F	12 51 55					

Porto Rico. *Vieques. Magnetic Observatory.* U. S. Coast and Geodetic Survey. H. M. Pease.

Lat., 18° 09′ N.; long., 65° 27′ W. Elevation, 19.8 meters.

Instruments: Two Bosch-Omori.

Instrumental constants.. E: V 10, T_0 21.4; N: V 10, T_0 21.1

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			H. m. s.	Sec.	μ	μ	Km.	
Apr. 18		eP_N	4 13 07	6				No well-defined phases.
		S_N	4 23 37	8				
		M_N	4 24 00			110		
		eS_E	4 24 27	5				
		M_E	4 25 05		120			
		F_E	5 10 00					
24		P_E	4 27 23	2				Reported to have been felt in Vieques, Porto Rico, and San Domingo. Record of N. was accidentally burned.
		L_E	4 27 55	9				
		M_E	4 28 15	8	1,300			
		C_E	4 35 00	5				
		F_E	4 49 00					
24		P_E	8 06 29					Record of N. was accidentally burned.
		S_E	8 10 31	12				
		L_E	8 11 53	24				
		M_E	8 13 01	20	1,340			
		C_E	8 23 00	10				
		F_E	8 40 00					
26		P_E	2 26 18	4				Times uncertain because of defective time of marking device.
		P_N	2 26 38	3				
		L_E	2 29 44	20				
		L_N	2 30 24	20				
		M	2 30 35	12	200	250		
		C	2 35 00	13				
		F	2 50 00					

TABLE 2.—*Instrumental reports, April, 1916*—Continued.

Vermont. *Northfield.* *U. S. Weather Bureau.* Wm. A. Shaw.

Lat., 44° 10′ N.; long., 72° 41′ W. Elevation, 256 meters.

Instruments: Two Bosch-Omori, mechanical registration.

Instrumental constants.. $\begin{cases} E & 10 & 15 \\ N & 10 & 16 \end{cases}$ (V, T_0)

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Apr. 2		e_E	8 36 20					
		L	8 42 20	12				
		F	9 00 00					
2		L?	19 03 20					
		F	19 10 00					
6		L	19 20 10					
		F	19 30 00					
7		e	9 45 42					
		S?	9 48 22					
		L	10 06 25	16				
		L	10 38 30	16				
		L	10 44 30	20				
		L	10 50 20	20				
		F	11 30 00					
11		eL	3 58 34	10				
		F	4 15 00					
15		e	12 51 23					
		L	14 05 00	12				
		F	14 15 00					
16		e_N?	22 42 06					Phases indeterminate.
		F	23 10 00					
18		P	4 11 44				6,225	
		S	4 19 32					
		L	4 28 30	8				
		L	4 38 30	12				
		F	6 10 00					
21		P?	11 49 35					
		S	11 55 45					
		L	12 03 33	14				
		F	13 00 00					
24		P	4 32 15				2,690	
		S	4 36 35					
		L	4 41 00	14				
		F	5 30 00					
24		P	8 09 10				3,700	
		S	8 14 40					
		L	8 19 30					
		M	8 26 00			2,300		Undamped pendulum.
		F	9 30 00					
26		P	2 28 30				3,420	
		S	2 33 42					
		L	2 36 50	24				
		F	3 30 00					
26		P?	6 32 36					
		S?	6 38 22					
		L	6 46 28	14				
		F	7 10 00					
26		P?	7 23 08					
		S?	7 28 50					
		L	7 36 20					
		F	8 00 00					
26		e	12 49 12					Phases uncertain.
		F	12 52 00					

Canada. *Ottawa.* *Dominion Astronomical Observatory.* Earthquake Station. Otto Klotz.

Lat., 45° 23′ 38″ N., long., 75° 42′ 57″ W. Elevation, 83 meters.

Instruments: Two Bosch photographic horizontal pendulums, one Spindler & Hoyer 80 kg. vertical seismograph.

Instrumental constants: 120 26 (V, T_0)

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Apr. 2		e	8 39 48					
		L	8 41 00	14				
		F	9 10 00					

Canada. *Ottawa.* *Dominion Astronomical Observatory*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Apr. 2		e_N	19 01 19					
		i	19 03 20					
		e_E	19 06 20	10				
		L_E	19 14 33	8				
		L_N	19 14 40	14				
		L_N	19 16 00	8				
		L_E	19 17 00	8				
		F	19 25 00					
6		L	19 18 36	20				
		L	19 20 00	14				
		F	19 35 00					
6		eL_E	20 52 24	14				
		L_N	20 53 00	14				
		F	21 00 00					
7		e	9 45 40					Traces of disturbance from 4h 45m on, till merged in this. No marked maximum.
		i	9 48 34					
		eL_E?	10 02 24	40				
		eL_E?	10 07 30	40				
		L_E	10 12 00	26				
		L	10 32 00					
			10 41 00	20				
		L	10 47 00	18				
		L	10 51 00					
			11 01 00	16				
		L_E	11 19 00	20				
		L_N	11 22 00	18				
		L_E	11 27 00					
			11 40 00	16				
		F	12 15 00					
11		eL	3 57 00	14				
		F	4 15 00					
14		e_N	20 33 48				6,000?	
		i	20 38 09					
		i	20 43 50					
		L_E	20 52 00	20				
		L_E	20 57 00	20				
		F	21 10 00					
14		e_E	21 48 10				6,000?	
		eL_E	22 03 00	24				
		L	22 06 00	20				
		L	22 09 00	18				
		L_E	22 18 00	15				
		F	22 30 00					
15		i	12 53 34				20.000?	
		i_N	13 05 07					
		i_N	13 23 00					
		i_N	13 39 59					
		L_E	13 44 30	30				
		L_E	13 49 00	23				
		L_E	13 52 00	20				
		L_E	13 56 00	20				
		L_E	14 04 00	17				
		F	14 35 00					
16		e_E	22 42 12					
		i_E	22 47 00	2				
		L_E	22 48 00	10				
		L_N	22 49 00	10				
		L	22 50 00	10				
		F	23 10 00					
18		*O*	*4 01 38*				6,250	
		iP	4 11 23	2				
		iS	4 19 13					
		eL	4 28 06	48				
		M	4 33 42	20	95	120		
		L	4 40 00	12				
		L	4 50 00	12–16				
		L	5 03 00	12				
		L	5 19 00	11–12				
		F	6 05 00					
21		e	11 49 12				10,000?	
		i_N	11 55 31					
		i_E	11 55 40					
		i_E	11 56 13					
		e	12 03 00	12				
		L_E?	12 06 00	18				
		L_N?	12 08 00	15				
		eL	12 15 24	40				
		L	12 19 00	20				
			12 35 00					
		L_E	12 41 00	16				
		L	12 45 00	14				
		L_E	12 54 00	18				
		L	13 02 00	16				
		L_E	13 12 00	16				
		F	13 30 00					

TABLE 2.—*Instrumental reports, April, 1916*—Continued.

Canada. *Ottawa. Dominion Astronomical Observatory*—Concluded.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 24		*O*	*4 26 32*				2,930	
		P	4 32 22	2				
		S	4 37 00	6-8				
		L_N	4 40 06	20				
		L_E	4 40 48	20				
		F	5 50 00					
24		*O*	*8 02 08*				3,840	
		P	8 09 14					
		S	8 14 52					
		L_N	8 18 30	30				
		L_E	8 18 42	40				
		L_N	8 20 00	40				
		M_E	8 22 00	20	100			
		M_N	8 26 18	16		280		
		L	8 40 00	15				
		L	8 49 00	15				
		L	9 02 00	13				
		F	10 00 00					

VERTICAL.

					A_Z			
		L	*8 23 32*					
			8 25 00	*19*				
		L	*8 26 00*					
			8 27 00	*14*				
		F	*8 30 00*					
24		P	16 08 17				220	Local quake.
		S	16 08 41					
		F	16 09 20					

VERTICAL.

					A_Z			
		P	*16 08 16*					
		S	*16 08 40*					
		F	*16 09 14*					
26		i	2 29 18					Record from "Deformation" instrument whose scale is 17 mm. to hour. No sheet on seismograph for Apr. 25 (Apr. 25-26).
		i	2 30 18					
		i_E	2 33 00					
		i_N	2 34 30					
26		i_N	6 34 00					
		i_N	6 38 24					
26		i_N	7 25 00					
		i_N	7 29 48					

Canada. *Toronto. Dominion Meteorological Service.*

Lat., 43° 40′ 01″ N.; long., 79° 23′ 54″ W. Elevation, 113.7 meters. Subsoil: Sand and clay.

Instrument: Milne horizontal pendulum, North. In the meridian.

Instrumental constant.. T_0 18. Pillar deviation, 1 mm. swing of boom=0.59″.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 2		L	8 40 42					P and S not recorded.
		M	8 41 00		*600			
		F?	8 56 36					
6		L	19 22 06		*50			
		F						
7		P	9 45 36					Dual?
		e	9 49 12					
		i	9 59 36					
		L	10 13 30					
		L	10 36 24					
		L	10 42 30					
		L	10 49 54					
		M	10 51 48		*1200			
		L	11 22 06					
		L	11 30 36					
		M	11 34 54		*1300			
		F	12 46 48					
7		e	15 56 54		*50			
		F	15 59 48					

* Trace amplitude.

Canada. *Toronto. Dominion Meteorological Service*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 11		L	3 56 48		*200			
		F	3 58 54					
14								Apr. 14 missed an earthquake. Visitors in seismograph room from 20^h 50^m to 21^h 04^m interferred with registration.
14		L	22 06 00					
		L	22 42 48		*200			
		F	22 43 54					
15		i	13 11 12					Prolonged L waves. Earthquake, Canary Islands.
		i	13 34 48					
		L	13 51 18					
		M	14 05 36		*500			
		L	14 18 06					
		L	14 25 24					
		L	14 35 54					
		F	14 50 18					
16		L	22 52 48					
		L	22 54 18					
		L	23 51 06		*200			
17		F?	0 13 48					
18		eP	4 11 24				6,216	Marked quake. Phases well defined.
		iP	4 15 18					
		iS	4 19 12					
		iS	4 25 00					
		L	4 29 48					
		M	4 40 42		*1,400			
		L	4 50 00					
		M	4 54 54		*1,200			
		L	5 50 48					
		L	6 32 30					
		F	7 02 00					
21		P?	11 49 48				5,550?	Marked quake.
		iS	11 57 00					
		iS	12 03 06					
		i	12 06 30					
		L	12 14 12					
		M	12 20 36		*1,500			
		L	12 58 00					
		F	13 52 24					
24		iP	4 32 18				2,908	Phases well defined.
		iS	4 36 54					
		L	4 38 24					
		M	4 38 24		*1,800			
		L	4 42 54					
		F	5 24 00					
24		P?	8 09 54				3,710	Marked quake.
		eP	8 12 42					
		iS	8 15 24					
		L	8 17 24					
		L	8 21 00					
		M	8 23 00		*11,000			
		L	8 24 06					
		M	8 25 36		*7,700			
		L	8 26 30					
		M	8 29 36		*6,000			
		L	8 44 54					
		F	11 22 00					
26		iS	2 33 12					P not recorded. Fairly large quake. Large double cigar-shaped movement.
		L	2 35 36					
		L	2 36 36					
		L	2 40 12					
		M	2 41 12		*11,000			
		M	2 43 48		*8,300			
		L	2 49 48					
		L	2 52 36					
		L	2 54 42					
		F	4 43 00					
26		e	6 39 48					Dual.
		L	6 43 06					
		M	6 46 12		*800			
26		e	7 30 24					P and S merged into previous quake.
		iL	7 33 18					
		M	7 39 30		*800			
		F	8 28 30					

* Trace amplitude.

TABLE 2.—*Instrumental reports, April, 1916*—Concluded.

Canada. *Victoria, B. C. Dominion Meteorological Service.*

Lat., 48° 24′ N.; long., 123° 19′ W. Elevation, 67.7 meters. Subsoil: Rock.

Instrument: Wiechert, vertical; Milne horizontal pendulum, North. In the meridian

Instrumental constant.. T_0 18. Pillar deviation, 1 mm., swing of boom=0.54″.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Apr. 2		P	8 22 55				830	
		S	8 23 25					
		L	8 23 55					
		M	8 24 40		*1,200			
		F	8 31 51					
			VERTICAL.					
					A_Z.			
		P		*2–3*			*640*	
		S	*8 24 10*	*5*				
		L	*8 24 10*	*8–10*	*15*			
		M	*8 24 35*	*10*				
		F	*8 42 52*					
6		P	19 03 53				180?	
		S	19 04 13					
		L	19 04 13					
		M	19 04 28		*200			
		F	19 06 51					
			VERTICAL.					
					A_Z.			
		P					*1,120*	
		S	*19 05 53*					
		L	*19 05 53*					
		M	*19 06 53*		*3*			
		F	*19 12 51*					
7		P?	10 04 23					
		L	10 10 49					
		M	10 10 59		*200			
		F?						
			VERTICAL.					
					A_Z.			
		P	*10 04 38*				3,070	
		S	*10 09 26*					
		L	*10 15 54*					
7		P	10 50 00				3,190?	
		S	10 54 57					
		L	10 59 25					
		M	11 06 22		*2,000			
		F	11 51 29					
7		L	16 12 06					
		F	16 19 36		*50			
11		P	3 39 27				830	
		L	3 40 57					
		M	3 41 27		*600			
		F	3 45 27					
14		L	20 52 36					
		M	20 54 06		*200			
		F	21 02 06					
14		L	21 54 06					
		M	21 55 06					
		F	?					

* Trace amplitude.

Canada. *Victoria, B. C. Dominion Meteorological Service*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Apr. 15		P	13 33 37				4,220	
		S	13 39 37					
		L	13 47 07					
		M	13 51 07		*200			
		F	?					
15		L	14 38 07					
		M	14 40 37		*300			
		F	15 33 07					
16		P	22 45 11					
		L	22 47 11					
		M	22 48 11		*400			
		F	23 00 11					
18		P	4 07 36				530	
		S	4 08 34					
		L	4 12 01					
		M	4 16 56		*1500			
		F	4 54 18					
			VERTICAL.					
					A_Z.			
		P	*?*	*2–3*				
		L	*4 12 06*	*7*				
		M	*4 18 31*	*7*	*7*			
		F	*?*					
21		P	11 43 01					
		L	11 51 57					
		M	11 51 57		*1100			
		F	13 07 19					
			VERTICAL.					
					A_Z.			
		P		*2–3*			*440*	
		S	*11 43 50*	*7*				
		L	*11 52 10*	*7*	*7*			
24		P	4 42 35				1,120	
		S	4 44 35					
		L	4 46 35					
		M	4 48 35		*400			
		F	5 34 35					
24		P	8 10 54				7,425	
		S	8 19 45					
		L	8 31 35					
		M	8 40 53		*1500			
		F	9 59 35					
			VERTICAL.					
					A_Z.			
		P	*8 11 30*				*7,600*	
		S	*8 20 30*					
		L	*8 32 30*		*7*			
		M	*8 42 00*					
26		P	2 32 36				7,425	
		S	2 41 27					
		L	2 45 52					
		M	2 59 39		*1200			
		F	3 45 23					
26		P	6 56 31					
		L						
		M	7 04 54		*300			
		F	7 13 55					
26		L	7 49 48					
		M	7 53 15		*200			

*Trace amplitude.

TABLE 3.—*Late seismological reports.* (*Instrumental.*)

Canada. *Toronto. Dominion Meteorological Service.*

Lat., 43° 40′ 01″ N.; long., 79° 23′ 54″ W. Elevation, 113.7 meters. Subsoil: Sand and clay.

Instrument: Milne horizontal pendulum, North. In the meridian.

Instrumental constant: . T_0 18. Pillar deviation, 1 mm. swing of boom=0.59″.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 1		L	19 52 30					
		M	19 55 12		*200			
		F	20 03 24					
4		e?	8 12 24					
		L	8 15 36					
		L	8 21 54					
		M	8 25 54		*300			
		F	8 50 30					
12		S?	7 44 30					P not visible, S doubtful.
		L	7 45 42					
		L	7 50 18					
		M	7 53 24		*300			
		F	8 06 00					
16		L	23 00 42					
		L	23 03 00					
		M	23 03 00		*300			
		F	23 09 36					
19		eL	13 08 48					
		L	13 14 18					
		M	13 16 18		*200			
		F	13 26 18					
26								A quake lost, clocks stopped on 25th until 18h of 26th.
28		e	7 56 12					
		eL	7 57 42		*200			
		F	8 12 00					
29		S	19 09 06					A minute vibration precedes 19h 9m 6s, but impossible to measure.
		L	19 11 36					
		M	19 15 30		*200			
		F	19 31 54					
31		L	11 28 42					Boom much steadier at 11h 29m 48s.
		L	11 31 24					
		M	11 31 24		*900			
		F	11 58 36					
31		L	16 35 42		*50			
		F	16 36 42					
31		L	16 55 12		*100			
		F	16 58 12					

* Trace amplitude.

Canada. *Victoria, B. C. Dominion Meteorological Service.*

Lat., 48° 24′ N.; long., 123° 19′ W. Elevation, 67.7 meters. Subsoil: Rock.

Instrument: Wiechert, vertical; Milne horizontal pendulum, North. In the meridian.

Instrumental constant.. T_0 18. Pillar deviation, 1 mm. swing of boom=0.54″.

Reports for first half of February published in WEATHER REVIEW for February, 1916.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Feb. 15		P	11 40 06				2,230	
		S	11 43 48					
		L	11 45 48					
		M	11 46 48		*6000			
		F	12 41 48					
20		P	17 50 36				1,910	
		S	17 53 54					
		L	17 58 06					
		M	18 14 54		*1500			
		F	19 49 12					
22		P	19 21 36					22d local tremor felt at 4 a. m. in city, not recorded.
		L	19 22 06					
		M	19 22 24		*300			
		F	19 24 18					
27		P	20 30 24				4,960	
		S	20 37 00					
		L	20 43 00					
		M	20 55 36		*8000			
		F	22 43 00					
		VERTICAL.			A_Z.			
		P	*20 31 00*					
		S	*20 38 00*					
		L	*20 44 10*					
		M	*20 56 00*		*30*			
		F						

* Trace amplitude.

Canada. *Victoria, B. C. Dominion Meteorological Service*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1916.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 1								March 1 light turned down at 19h 53m to attend to instrument. Quake, if any, was missed.
4		P	7 39 25				8,210	
		S	7 48 55					
		L	7 54 22					
		M	7 57 51		*1,000			
		F	8 27 36					
12		P	7 48 28				1,420?	
		S	7 50 57					
		L	7 54 25					
		M	7 59 53		*400			
		F	8 10 54					
15		P	22 40 06				500	
		S	22 41 06					
		L	22 42 35					
		M	22 44 34		*1500			
		F	22 51 30					
19		P?						
		S	12 49 05					
		L	12 52 04					
		M	13 00 30		*200			
		F	13 19 50					
26			{ 0 46 30 0 54 30 }					There appears a thickening, but impossible to measure.
28		P	7 36 25				450	
		S	7 37 15					
		L	7 38 25					
		M	7 39 10		*500			
		F	7 48 55					
29		P	19 20 58					
		S	19 22 58					
		L	19 24 18					
		M	19 24 28		*200			
		F	19 27 58					
31		P	11 11 24				400	Probably off Vancouver Island.
		S	11 12 08					
		L	11 12 53					
		M	11 13 23		*4500			
		F	11 26 17					
		VERTICAL.			A_Z.			
		P	*11 11 39*	*2*			*450*	
		S	*11 12 25*	*5*	*85*			
		L	*11 12 50*	*7-10*				
		M	*11 13 25*	*6*				
		F	*11 32 35*					
31		P	16 36 57				590	
		S	16 38 02					
		L	16 38 41					
		M	16 39 01		*600			
		F	16 44 08					
		VERTAL.			A_Z			
		P	*16 37 45*	*2*			*320*	
		S	*16 38 20*	*4*				
		L	*16 38 45*	*8-9*				
		M	*16 39 00*	*7-8*	*17*			
		F	*16 52 00*					

* Trace amplitude.

SEISMOLOGICAL DISPATCHES.[1]

Fuerteventura, Canaries, Apr. 15, 1916 (via Paris, Apr. 20, 1916).

An earthquake lasting 12 seconds rocked the houses of this island to-day. The shock was accompanied by loud grumblings, and terrified the population. The damage was small. (*Assoc. Press.*)

Santo Domingo, Dominican Republic, Apr. 24, 1916.

A severe earthquake occurred here at 11:30 o'clock last night. No damage was caused. (*Assoc. Press.*)

San Juan, P. R., Apr. 24, 1916.

An earthquake lasting 10 seconds occurred at 12:30 o'clock this morning. No damage was done. (*Assoc. Press.*)

Boise, Idaho, Apr. 29, 1916.

A distinct earthquake shock was felt here at 8:18 o'clock to-night. The wave proceeded from east to west. No damage has been reported. (*Assoc. Press.*)

Boise, Idaho, Apr. 30, 1916.

A slight earthquake shock was felt here to-night at 8:20 p. m. It was especially noticeable to occupants of office buildings. (*United Press.*)

[1] Reported by the organization indicated and collected by the seismological station at Georgetown University.

SECTION VI.—BIBLIOGRAPHY.

RECENT ADDITIONS TO THE WEATHER BUREAU LIBRARY.

C. FITZHUGH TALMAN, Professor in Charge of Library.

The following have been selected from among the titles of books recently received as representing those most likely to be useful to Weather Bureau officials in their meteorological and seismological work and studies:

Alexander, William H.
What the United States Weather Bureau is doing in California. (*In* Cleveland engineering society. Journal. March, 1916. v. 8, p. 333–355.)

Beach, S. A., & Allen, F. W., jr.
Hardiness in the apple as correlated with structure and composition. Ames, Iowa. 1915. 2 p. l., 158–204 p. 22 cm. (Iowa agric. exper. station. Research bulletin no. 21.) [Comparison of varieties as to resistance to cold, p. 201–204.]

Belden, William S.
The climate of Brown County, Kansas. n. p. 1916. 20 p. 23 cm.

Birkinbine, Carl Peter.
Variations in precipitation as affecting water works engineering. [With discussions.] Philadelphia. [1916.] 103 p. 23½ cm. (*Reprint:* Journal of American water works association, v. 3, no. 1.)

Bouches-du-Rhône. Commission de météorologie.
Bulletin annuel. 1914, 33e anné. Marseille. 1915. v. p. 28½ cm. [Contains "Documents relatifs au climat de Marseille," [by Henry Bourguet], p. i–xxiv.]

Eredia, Filippo.
Sulla misurazione della rugiada. Firenze. 1915. 11 p. plate. 24½ cm. (*Estratto:* L'agricoltura coloniale, anno 9, num. 12, Dicembre 1915.)

Georgeson, C. C.
Information for prospective settlers in Alaska. Washington. 1916. 30 p. plates. 23½ cm. (Alaska agric. exper. station. Circular no. 1.) [Climate, p. 5–8.]

Great Britain. Meteorological committee.
Tenth annual report, for the year ended 31st March, 1915. London. 1915. 93 p. 24½ cm.

Hildebrandsson, H. H.
Sur le prétendu changement du climat Européen en temps historique. Upsala. 1915. 31 p. 3 pl. 29 cm. (Nova acta regiae societatis scientiarum Upsaliensis, ser. IV, v. 4, n. 5.)

International catalogue of scientific literature.
Twelfth annual issue. F. Meteorology. London. 1915. viii, 194 p. 21½ cm. (Published for the International council by the Royal society of London.)

Kodaikanal and Madras observatories.
Annual report of the director, 1915. Madras. 1916. 2 p. l., 24 p. 33½ cm.

Mysore. Meteorological department.
Report on rainfall registration in Mysore for 1914, by N. Venkatesa Iyengar. Bangalore. 1916. xvii, 49 p. plates. maps. 31 cm.

Ôsaka meteorological observatory.
Seismological observations in Ôsaka, 1915. Ôsaka. 1916. 30 p. plates. 26 cm. (Annual report, part II.)

Ruppel, S.
Gebäudeblitzschutz. (*In* Elektrotechnische Zeitschrift. Berlin. 5. Juni 1913. 34. Jahrg., p. 643–647.)

Satô, Shinzô.
On the diurnal variation of underground temperature. Sendai, Japan. 1916. 393–405 p. 4 pl. 26 cm. (*Reprint:* Science reports of the Tôhoku imperial university, vol. IV, no. 5.)

Straits Settlements.
Meteorological returns, 1915. Singapore. 1916. unp. 33½ cm.

Tippenhauer, L. G.
Die elektromagnetische Theorie des Wetters. 3. Teil. Port-au-Prince. 1916. 23 p. plate. 29½ cm.

Turkestan. Hydrometric service.
Otchet, 1913. Petrograd. 1915. 6 v. 26½ cm. [Most of text is in Russian; table of contents and abstract of the report are also in French and English. Meteorology (English abstract), vol. 1, p. 170 ffg. Report on meteorological observations (in Russian), by E. Oldekop, vol. 2, p. 217 ffg. Register of meteorological observations, vol. 4, p. 295 ffg.]

U. S. National advisory committee for aeronautics.
First annual report, 1915. Washington. 1916. plates. 25½ cm.

Valle di Pompei. Osservatorio Pio X.
Riassunto delle osservazioni meteorologiche, 1914. [Valle di Pompei. 1916.] 14 p. 2 tables. 24 cm.

Ware, Horace E.
Notes on the term Indian summer. Cambridge. 1916. p. 123–130. 24 cm. (*Reprint:* Publications of the Colonial society of Massachusetts, vol. 18.) [See this issue of the REVIEW, p. 207.]

Whipple, Robert S.
Instruments for the measurement of solar radiation. London. 63 p. 21½ cm. (Transactions of the Optical society, London, sess. 1914–1915.)

RECENT PAPERS BEARING ON METEOROLOGY AND SEISMOLOGY.

C. FITZHUGH TALMAN, Professor in Charge of Library.

The subjoined titles have been selected from the contents of the periodicals and serials recently received in the Library of the Weather Bureau. The titles selected are of papers and other communications bearing on meteorology and cognate branches of science. This is not a complete index of the meteorological contents of all the journals from which it has been compiled. It shows only the articles that appear to the compiler likely to be of particular interest in connection with the work of the Weather Bureau.

Aeronautics. London. v. 10. May 3, 1916.
Diehl, Charles Vidal. Zeppelin weather fallacies. p. 288.

American society of civil engineers. Proceedings. New York. v. 42. May, 1916.
Duryea, Edwin, jr., & Haehl, H. L. A study of the depth of annual evaporation from Lake Conchos, Mexico. Discussion by M. Hegly, Robert E. Horton, and J. W. Ledoux. p. 787–796.
Chittenden, H. M., & Fuller, Myron L. Discussion on [the Progress report of the Special committee on] floods and flood prevention. p. 797–819.

Astrophysical journal. Chicago. v. 43. April, 1916.
Biscoe, Felix. The temperature and radiation of the sun. p. 197–216.

Engineering news. New York. v. 75. May 11, 1916.
Memphis flood protection. p. 890–894.

Indian meteorological department. Memoirs. Calcutta. v. 21. pt. 13. 1916.
Harrison, E. P. On the Calcutta standard barometer. p. 119–130.

Nature. London. v. 97. 1916.
Shaw, W[illiam] N[apier]. Illusions of the upper air. A review of progress in meteorological theory in England since 1866. p. 191–194; 210–213. (April 27, May 4.)

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Lyons, H[enry] G[eorge]. The winter climate of the eastern Mediterranean. p. 65–84.
Mr. J. B. Jordan. p. 84. [Obituary.]
Brooks, C. E. P. The rainfall of Nigeria and the Gold Coast. p. 85–106.
Sutton, J[ohn] R[ichard]. South African coast temperature. p. 107–111.

Science abstracts. London. v. 19. April 25, 1916.
Everdingen, E. van. Propagation of sound in the atmosphere. 162–163. [Abstr. Proc. K. Acad., Amsterdam.] [*See* Monthly Weather Review, May, 1916.]
Oddo, G[iuseppe]. Spontaneous ionisation of the aqueous vapour of the atmosphere. p. 164. [Abstr. from Gazz. Soc. chim. Ital.] [*See* Monthly Weather Review, May, 1916.]

Scientific American. New York. v. 114. May 20, 1916.
Abbe, Cleveland. How the United States weather bureau was started. p. 529. [See this REVIEW, p. 206.]

Scientific American supplement. New York. v. 81. May 13, 1916.
Dodwell, G. F. Note on the transparency of the atmosphere in central Australia. p. 311.
Measuring snowfall. p. 317. [Abstract of article by Mougin.]

Seismological society of America. Bulletin. Stanford University. v. 6. March, 1916.

Palmer, Andrew H. California earthquakes during 1915. p. 8–25.

Brasch, Frederick E. An earthquake in New England during the colonial period. p. 27–42.

Report of scientific committee on the Rossi-Forel scale. p. 43–45.

Symons's meteorological magazine. London. v. 51. April, 1916.

Bonacina, L. C. W. The great snowstorms of 1916. p. 37–40.

The hurricane in Jamaica, August 12th and 13th, 1915. p. 43.

U. S. Department of agriculture. Journal of agricultural research. Washington. v. 6. May 15, 1916.

Willaman, J. J., & West, R. M. Effect of climatic factors on the hydrocyanic-acid content of sorghum. p. 261–272.

Académie des sciences. Comptes rendus. Paris. Tome 162. 25 avril 1916.

Bigourdan, G. Distribution mensuelle de la nébulosité moyenne en France. p. 620–623. [With charts of monthly and yearly isonephs.]

Mathias, E. Sur trois observations d'éclairs en boule faites au sommet du Puy-de-Dôme. p. 642–643.

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[Bourget, Henry.] Documents rélatifs au climat de Marseille. p. i–xxiv.

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Hemel en dampkring. Den Haag. 13 jaargang. Maart 1916.

Stok, J. P. van der. Het klimaat van Nederlandsch-Indië. p. 169–172.

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Platania, Giovanni. Osservazioni dei punti neutri della polarizzazione atmosferica eseguite in Catania nel 1915. p. 52–56.

SECTION VII.—WEATHER AND DATA FOR THE MONTH.

THE WEATHER OF THE MONTH.

P. C. DAY, Climatologist and Chief of Division.

[Dated: Weather Bureau, Washington, June 3, 1916.]

PRESSURE.

The distribution of the mean atmospheric pressure over the United States and Canada and the prevailing direction of the winds are graphically shown on Chart VII, while the average values for the month at the several stations, with the departures from the normal, are shown in Tables I and III.

For the month as a whole the mean barometric pressure was below the normal in the extreme southern portions of California and Arizona and throughout all sections east of the Mississippi, except the western portion of Tennessee and in Alabama, Mississippi, and the extreme eastern Canadian provinces. For all other sections it was above the normal. The positive departures were generally small, the greatest values appearing in the north Pacific and the central Plains States. Likewise the negative departures were not marked, they being greatest in the region of the Great Lakes and in the New England States.

The month opened with relatively high pressure throughout practically all sections of the country, except in the region of the Great Lakes, most of Texas, Nevada, and California, where it was near or somewhat below normal. A succession of rather marked low-pressure areas moved across the southern half of the country and pressure below the normal predominated throughout the south and southeast generally until near the end of the first decade, when a rather extensive high area moved in from the northwest and overspread the south-central and southeastern districts.

Pressures above the normal predominated over most northern sections during the greater part of the first decade. However, toward the latter part of the decade and throughout most of the second decade, a number of rather extensive low-pressure areas crossed the northern and central portions of the country, while in the south relatively higher pressure obtained throughout the greater part of the second decade.

During the first few days of the third decade the pressure was generally low throughout most central and eastern districts, after which relatively high pressures overspread most sections, continuing during the greater part of the remainder of the month. The month closed with high pressure over practically the whole country, except from western Texas to southern California, where it was below the normal.

The distribution of highs and lows was generally favorable for westerly and northwesterly winds in the New England and Middle Atlantic States, the Lake region, the Missouri and upper portions of the Mississippi and Ohio Valleys, southerly and southwesterly along the South Atlantic coast and in the western Gulf States. Elsewhere variable winds prevailed.

TEMPERATURE.

The temperature during the first decade was much lower than the normal in the central part of the country. It averaged 12 degrees a day below the normal in the central Mississippi Valley, while it was slightly above normal in much of the region to westward of the Rocky Mountains. During this period the line of freezing temperature extended to the northern part of the Gulf States and it was only slightly above zero in the extreme north-central part of the country. Temperatures within 1 degree of the lowest ever recorded during the month of April occurred in several of the Gulf States. On the other hand, temperatures close to the highest ever recorded during the first decade of April occurred in portions of Idaho, Wyoming, and Arizona.

During the latter part of the decade, temperatures near the freezing point occurred throughout the great Central Valleys with heavy and killing frosts almost to the Texas coast as well as in Arkansas, northern Louisiana and eastward to southern Georgia, and light frosts as far south as northern Florida.

During the early part of the second decade the temperature was above normal in all central districts, while frosts occurred in portions of the north Pacific States and freezing weather prevailed in the Mountain States. During the next few days considerably cooler weather overspread the Central Valleys and extended to the Atlantic, with temperatures below the normal, and frosts in the Ohio Valley. The decade closed with generally warmer weather in the eastern part of the country, and with temperatures below the normal west of the Mississippi, while freezing weather obtained in North Dakota, Montana, the Rocky Mountain States, and parts of Oregon.

The third decade opened with freezing weather in the northern Plains States and as far south as central Nebraska, and frosts extended into the Ohio Valley and Lake region during the next few days, with cool weather generally in most eastern districts. Temperatures below the seasonal average prevailed over practically all districts east of the Rocky Mountains during the remainder of the month, with frosts in the Plains States, upper Mississippi Valley, lower Ohio Valley, and Lake region. The temperatures were somewhat above normal in the central and south Pacific Coast States.

For the month as a whole the mean temperature was above the normal in the region of the Great Lakes, northern Pennsylvania, New York, the northern portions of the New England States, along the Atlantic seaboard from New Jersey to northern Florida, and from the Rocky Mountain region westward to the Pacific. Elsewhere it was below the average.

PRECIPITATION.

The precipitation during the first decade of April was very unevenly distributed. The heaviest falls occurred in west-central Florida and from western Texas to

southern Missouri, while over much of the upper Mississippi and Missouri Valleys, most of the Plateau, and the southern Pacific coast districts, as well as over the Rocky Mountains, southern Texas, and the central Missouri Valley, the precipitation was light.

During the first half of the second decade the precipitation was generally light, while in small areas along the south Atlantic coast and in the central Ohio Valley no rain occurred. During the latter half of the decade widespread rains fell throughout practically all the central part of the country, as well as southward to the Gulf coast, but practically no rain occurred in Florida and over large areas in the Southwest, including the southern Plateau and southern Pacific coast regions and small districts on the middle Atlantic coast.

During the early part of the third decade moderate to heavy rains occurred at many points in the central part of the country, while light rain fell in most of Florida and light to moderate falls occurred in central and southern Texas. During the latter half of the decade light rains fell in portions of Texas, the great Central Valleys, the North Pacific and northern Rocky Mountain regions, and from the Great Lakes eastward, while over large areas in the Southeast and over the south Pacific coast little or no rain fell.

For the month as a whole the rainfall was heavy from central and eastern Texas northeastward to southern Missouri, moderate to heavy in the southern portions of Alabama, Mississippi, and Louisiana, west-central Florida, southern New York, northern Pennsylvania, the southeastern portion of the New England States, and the north Pacific coast. Elsewhere it was light, with only a trace or no precipitation in much of the Southwest, including most of California.

SNOWFALL.

During the first decade the snowfall was heavy in parts of the upper Mississippi Valley, and general snows fell in the Ohio and lower Missouri Valleys, and considerable amounts occurred as far south as the middle Atlantic coast. During the last decade some snow fell in the northern part of the country, and at the close of the month much snow still remained in the high elevations of the Rocky Mountains.

GENERAL SUMMARY.

The cool weather in the central and northern parts of the country retarded the development of vegetation, and farm work was somewhat delayed in the northeastern States, while in the south and east conditions were generally favorable.

Corn planting progressed favorably, but was somewhat later than usual. The cool weather toward the latter part of the month prevented proper germination and retarded growth in some sections.

The weather was favorable for the development of winter wheat, and the preparation of the ground and the planting of spring wheat progressed satisfactorily in the southern part of the spring wheat region, while in the northern portions the work was delayed by the cold, stormy weather.

Favorable weather for work in the cotton fields prevailed generally, but it was too cool for proper germination and growth in some sections; it was also too dry in some localities.

The weather was generally favorable for meadows and pastures, except that it was too dry in California and parts of the Southeast. Truck crops in some sections were damaged by frost, and cold weather retarded their growth in the central districts, and lack of rainfall was felt in the extreme South and Southeast.

The condition of fruits was generally favorable, although some damage resulted from frost and cold weather.

LOCAL STORMS.

The following notes of severe storms have been extracted from reports of Weather Bureau officials:

Louisiana.—Destructive winds, covering small areas, occurred in the vicinity of New Orleans at about 3 a. m. on April 7, 1916. At Gentilly Terrace, a suburb of the city, three houses were totally destroyed, three were badly damaged, and seven others were more or less damaged. The débris was carried forward in a straight line, the wind blowing from the southwest to northeast. The greatest width of the storm was about 250 feet and the length of its path was approximately one-fourth of a mile. About 1 mile a little south of east of Gentilly Terrace, a three-story building, which served as an orphan asylum for colored children, was wrecked in a peculiar manner. The upper story settled slowly down upon the two lower stories, which were compressed into a space of a few feet, but the upper story was but slightly damaged and the children in it escaped unhurt. Nearly 4 miles southeast of Gentilly Terrace, the roof of an elevator was blown off. At 2 a. m., an hour before the storm at Gentilly Terrace, there were high winds in the vicinity of Lutcher, about 30 miles west of New Orleans, where several houses were unroofed and two buildings destroyed. In the suburbs of New Orleans two persons were killed and four were wounded. In the vicinity of Lutcher one person was injured.

Alabama.—About 4.40 p. m., April 20, 1916, a tornado swept over Pine Grove, a small village 6½ miles west-northwest from Mobile. The track of the storm extended from south-southwest to north-northeast, and was about 80 feet wide and 3,000 feet in length. At its beginning, a frame building was lifted bodily and its parts carried away. Of the contents of the house, the piano was deposited 125 feet southeast of where the house stood; the only inmate, a woman, was killed and her body carried 300 feet to the north; the kitchen range was carried 500 feet to the north, a bedquilt 3 miles north, and a tornado insurance policy 7 miles northeast. Another house 30 feet to the northeast and a garage 200 feet east-southeast were demolished, and a house 300 feet east-northeast was moved 2 feet on its foundation. Except for the carrying away of the metal roof of a barn, no other material damage was done until a point 1,000 feet from the first building destroyed was reached, where a house occupied by a woman and two children was razed and the roof, walls, and contents were deposited about 80 feet to the north. The occupants were rendered unconscious but not seriously injured. The storm then entered a forest, where prostrate trees mark its path.

Average accumulated departures for April, 1916.

Districts.	Temperature.			Precipitation.			Cloudiness.		Relative humidity.	
	General mean for the current month.	Departure for the current month.	Accumulated departure since Jan. 1.	General mean for the current month.	Departure for the current month.	Accumulated departure since Jan. 1.	General mean for the current month.	Departure from the normal.	General mean for the current month.	Departure from the normal.
	°F.	°F.	°F.	Ins.	Ins.	Ins.	Per ct.		Per ct.	
New England	43.3	−0.4	− 4.3	3.19	−0.10	−2.50	6.6	+1.1	76	+ 3
Middle Atlantic	50.4	−0.3	− 0.1	2.44	+0.20	−1.40	6.2	+1.0	68	+ 1
South Atlantic	61.0	−0.2	+ 6.6	1.88	−1.60	−7.30	4.3	−0.3	64	− 8
Florida Peninsula	71.0	−2.4	− 1.1	1.23	−0.70	−5.10	4.0	+0.2	73	− 1
East Gulf	63.3	−1.3	+ 4.5	2.73	−1.30	−8.50	4.3	−0.6	66	− 4
West Gulf	63.5	−2.2	+ 8.2	3.63	+0.10	−2.40	5.3	+0.2	71	− 1
Ohio Valley and Tennessee	53.3	−1.4	+ 0.3	2.34	−1.20	−1.10	6.7	+1.4	67	+ 2
Lower Lakes	45.5	+0.4	− 2.4	2.34	0.00	+0.60	6.5	+0.8	75	+ 5
Upper Lakes	41.8	+1.0	− 2.6	2.59	+0.30	+0.90	6.3	+0.8	76	+ 3
North Dakota	39.7	−1.0	−10.9	1.52	−0.40	+0.50	5.6	+0.3	60	− 8
Upper Mississippi Valley	49.3	−1.2	+ 0.5	2.46	−0.50	+0.60	4.9	−0.3	68	0
Missouri Valley	48.8	−1.6	+ 0.5	2.35	−0.50	−2.80	6.3	+0.7	63	− 2
Northern slope	43.4	+0.6	− 3.8	0.82	−0.80	−0.70	4.5	−0.6	61	+ 3
Middle slope	50.5	−3.2	+ 1.8	2.60	−0.40	−0.80	6.1	+1.5	66	+ 9
Southern slope	60.2	−2.2	+12.5	2.31	+0.40	−0.80	4.3	−0.4	48	− 7
Southern Plateau	58.6	−0.8	+ 3.8	0.52	0.00	+1.80	2.6	−0.2	40	+10
Middle Plateau	50.3	+1.4	+ 4.9	0.38	−0.80	+0.60	4.1	−0.4	42	− 3
Northern Plateau	49.8	+0.8	− 2.7	0.97	−0.40	+1.10	4.5	−0.7	53	− 4
North Pacific	49.6	+0.5	− 3.9	3.33	+0.10	+5.50	6.6	+0.4	77	+ 6
Middle Pacific	56.3	+2.7	+ 4.8	0.36	−1.70	+1.10	2.6	−1.8	63	− 9
South Pacific	61.0	+3.0	+ 4.8	0.06	−1.00	+5.20	2.5	−1.5	69	+ 1

WEATHER CONDITIONS ON THE NORTH ATLANTIC DURING APRIL, 1915.

The data presented are for April, 1915, and comparison and study of the same should be in connection with those appearing in the REVIEW for that month. Chart IX (XLIV–54) shows for April, 1915, the averages of pressure, temperature, and the prevailing direction of the wind at 7 a. m., 75th Meridian time, together with the locations and courses of the more severe storms of the month.

PRESSURE.

The average pressure for the month over the ocean as a whole was somewhat above the normal. The Azores high, with a crest of 30.3 inches, was not far from its usual position, while the Continental HIGH, crest of 30.1 inches, was central near Asheville, N. C., extending as far east as the 74th meridian. The isobar of the lowest mean pressure, 29.7, inches, was about 5 degrees north of its usual position as it appears on the Meteorological Chart of the North Atlantic Ocean showing normal pressure for April.

North of the fiftieth parallel the pressure was much lower during the first decade of the month than in the last 20 days, and in the regions between the sixtieth and sixty-fifth parallels, and the 1st and 20th meridians, west longitude, the mean pressure for the first 10 days ranged between 29.25 and 29.34 inches, while the average for the month was from 29.69 to 29.72 inches. The same conditions held true over the greater part of the ocean, although in the area covered by the Azores HIGH the mean pressure for the first decade was greater than that for the month.

STORMS.

North of the fiftieth parallel most of the heavy winds occurred in the first half of the month, while south of that line they were fairly well distributed throughout the month. The greatest number of gales observed in any 5-degree square was 7, a percentage of 23, and occurred in three different localities. Over the ocean as a whole the number of gales was slightly above the average, although there were a few exceptions.

On March 31 a LOW (I on Chart IX) of 28.60 inches was central near St. Johns, Newfoundland, winds of over 60 miles an hour prevailing near its center, while several vessels reported strong gales between St. Johns and the 30th Meridian. This disturbance moved in a southerly direction and on April 1 was near latitude 39°, longitude 55°, the barometer having risen to 29.26 inches while the wind still retained its force. The storm then recurved toward the northeast, and increasing in its rate of movement was near latitude 51°, longitude 37°, on the 2d. The barometer then began to rise and the storm area to increase, while its intensity decreased, although a number of vessels south of the center encountered westerly and southwesterly winds of gale force. The LOW continued in its northeasterly course with a nearly constant rate of movement, and on the 3d the approximate position of the center was latitude 49°, longitude 20°, although it was impossible to locate it accurately on account of the lack of observations. The barometer had fallen, however, to 28.90 inches, and westerly and southwesterly winds of over 60 miles an hour, accompanied by hail, were reported. It evidently continued on its northeasterly course, as evidences of its presence could still be seen on the 4th, although it was impossible to plot the center.

On the 2d there was a large and rather shallow area of low pressure (II on Chart IX) central near Habana, Cuba. The winds ranged from light to moderate, with a minimum barometer reading of 29.80 inches. This LOW traveled swiftly in a northeasterly direction, gaining in intensity, and on the 3d was about 4 degrees east of Hatteras, winds of from 50 to 65 miles, accompanied by hail and snow, prevailing within the storm area. The storm continued in its northeasterly movement, parallel to the coast, and on the 4th the center was about 5 degrees east of Nantucket, the conditions of wind and weather remaining about the same as on the day before, although the storm area was of greater extent, winds of gale force being reported as far east as the 50th Meridian. From this point the area of low pressure spread out to such a degree that it was impossible to locate its center. On the 5th, winds of gale force prevailed over the central portion of the northern sailing routes and also near latitude 58°, longitude 13° west.

Between April 6 and 9 an area of low pressure covered a large portion of the North Sea and the adjacent mainland of Europe, gales being reported during the first three days of that period, but the wind moderated on the 9th. From the 10th to the 16th no serious disturbances were reported over the North Atlantic and moderate to light winds prevailed over the entire area.

On April 17 a LOW (III on Chart IX) appeared about 3 degrees west of Bermuda. Two vessels near the center reported north and northeast winds of from 40 to 50 miles an hour, while between the 68th meridian and the American coast light airs and clear weather prevailed. This disturbance moved in a northeasterly direction, increasing in extent and violence, and on the 18th was near latitude 37°, longitude 63°, strong gales of over 60 miles an hour being reported by two vessels. While the storm covered a larger territory than on the previous day, it was still of limited extent, as only moderate winds were reported from the waters adjacent to the American coast. The LOW continued in its northeasterly course and on the 19th was near latitude 40°, longitude 62°, with gales pre-

vailing near the center, although as on the previous day the storm area was limited. The disturbance then turned toward the north and on the 20th was central in the Gulf of St. Lawrence, with a minimum barometer reading of 29.35 inches. A HIGH with a crest of 30.6 inches was near latitude 45°, longitude 30°, at the same time and the steep gradient between these two areas caused heavy winds in the intermediate region. By the 21st the center of the LOW had moved about 7 degrees east of its position on the 20th, the barometer having risen, and the wind decreased in force. The conditions of wind and weather during the remainder of the month was practically normal, as no unusual disturbances were reported.

TEMPERATURE.

Over the ocean as a whole, north of the 30th parallel, the temperatures were somewhat above the normal, although in most cases the departures were small. In the waters adjacent to the European coast they ranged from 0° off the coast of Scotland to +3° between the 35th and 40th parallels, while in midocean the extreme range was from −1° to +4°. In the waters adjacent to southern Canada and the northern part of the United States the temperature was from 2 to 4 degrees above the normal, the excess decreasing southward to 0 degrees off the coast of South Carolina, south of which point the departures were negative. The temperature departures at a number of Canadian and United States Weather Bureau Stations on the Atlantic and Gulf coasts were as follows: St. Johns, N. F., +4.3°; Sydney, C. B. I., +3.2°; Halifax, N. S., +3.2°; Eastport, +1.3°; Portland, +2.8°; Nantucket, +1.3°; New York, +5.3°; Washington, +6.3°; Norfolk, +4.2°; Hatteras, +1.2°; Charleston, −0.5°; Miami, −4.7°; Key West, −3.3°; Pensacola, −1.7°; New Orleans, +0.9°; Galveston, −2.6°; Corpus Christi, −2.5°.

The lowest temperature reported during the month was 18° and occurred on the 9th and 10th in the five-degree square between latitude 50°–55° and longitude 55°–60°. The highest temperature recorded was 82° and occurred on several days in the waters adjacent to the Panama Canal Zone.

FOG.

During the period from 1901 to 1906, for the month of April, the average percentage of fog off the banks of Newfoundland was 40 or more. In the same locality for April, 1915, fog was observed on 10 days, a percentage of 33. In the waters adjacent to the American coast between the 40th and 45th parallels the normal percentage is from 20 to 30, while for the month under discussion it was observed on 10 days, a percentage of 33. Along the sailing routes the amount of fog varied but little from the normal, as it was slightly above in some localities and below in others.

PRECIPITATION.

Hail occurred on the 3d, 4th, 5th, 6th, 7th, 8th, 9th, and 20th on the northern sailing routes and snow on the 2d, 3d, 4th, 6th, 24th, and 25th.

Maximum wind velocities, April, 1916.

Stations.	Date.	Velocity.	Direction.	Stations.	Date.	Velocity.	Direction.
		Mis./hr.				*Mis./hr.*	
Buffalo, N. Y.	6	52	sw.	New York, N. Y.	12	54	nw.
Do.	14	56	w.	Do.	14	72	nw.
Do.	20	52	w.	Do.	15	50	n.
Cape May, N. J.	15	50	nw.	Do.	18	72	nw.
Columbia	17	51	nw.	Norfolk, Va.	14	62	w.
Dayton, Ohio	20	52	sw.	North Head, Wash	16	48	s.
Duluth, Minn.	19	53	ne.	Do.	17	60	s.
Eastport, Me.	9	50	ne.	Do.	26	70	se.
Erie, Pa.	20	52	w.	Oklahoma, Okla.	29	50	s.
Louisville, Ky.	24	52	w.	Pittsburgh, Pa.	14	52	nw.
Lexington, Ky.	20	56	w.	Do.	17	50	w.
Lynchburg, Va.	14	51	nw.	Pensacola, Fla.	7	52	s.
Mt. Tamalpais, Cal	10	84	nw.	Point Reyes			
Do.	11	84	nw.	Light, Cal.	10	64	nw.
Do.	12	56	n.	Do.	11	87	nw.
Do.	13	52	n.	Do.	12	51	nw.
Do.	14	61	nw.	Do.	14	61	nw.
Do.	15	71	nw.	Do.	17	50	nw.
Do.	17	83	nw.	Do.	20	50	nw.
Do.	18	80	nw.	Do.	28	64	nw.
Do.	21	62	nw.	Sandy Hook, N. J.	14	59	nw.
Do.	22	61	nw.	Do.	18	52	nw.
Do.	27	68	nw.	St. Paul, Minn.	19	64	e.
Do.	28	70	nw.	Trenton, N. J.	14	52	nw.
Do.	20	56	nw.	Do.	18	50	nw.
Nantucket, Mass.	14	50	n.	Toledo, Ohio	17	58	w.
Nashville, Tenn.	20	62	w.				

CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, April, 1916.

Section.	Temperature.								Precipitation.					
	Section average.	Departure from the normal.	Monthly extremes.						Section average.	Departure from the normal.	Greatest monthly.		Least monthly.	
			Station.	Highest.	Date.	Station.	Lowest.	Date.			Station.	Amount.	Station.	Amount.
	° F.	° F.		° F.			° F.		In.	In.		In.		In.
Alabama	62.2	−0.9	Ozark	93	15	Valley Head	29	10	3.14	−1.15	Bay Minette	8.00	Camp Hill	1.15
Arizona	60.2	+1.1	2 stations	103	24†	Fort Valley	11	1	0.47	−0.11	Marquette Ranger Sta.	2.13	11 stations	T.
Arkansas	59.9	−1.2	do	92	14	Pond	24	9	3.65	−1.25	Dutton	7.46	Whitecliffs	2.00
California	57.1	+0.1	Greenland Ranch	104	27	Madeline	11	19	0.52	−1.27	Crescent City	6.43	36 stations	0.00
Colorado	42.9	−0.7	3 stations	88	11†	Hermit	− 7	1	1.88	+0.05	Fairview	7.10	Palisades	0.10
Florida	68.1	−1.5	Plant City	94	19	Fenholloway	29	10	2.30	−0.12	Fort Meyers	5.61	Key West	0.24
Georgia	62.5	−0.6	2 stations	95	15	Clayton	25	10	1.82	−1.57	Fair View	3.46	Lumber City	0.76
Hawaii (March)	70.3	......	Mahukona, Hawaii	90	31	2 stations	48	16†	8.54	......	Keanae Valley, Maui	22.26	Mahukona, Hawaii	1.96
Idaho	46.2	+0.6	Glenns Ferry	90	26	Pierson	5	7	1.04	−0.44	Castle Creek	6.53	Shoshone	T.
Illinois	50.9	−1.3	2 stations	86	12	Sycamore	19	6	1.64	−1.70	New Burnside	3.87	Elgin	0.68
Indiana	50.4	−1.1	Madison	85	19	Knox	19	8	2.49	−0.74	Shelbyville	5.10	Kokomo	0.69
Iowa	47.1	−1.6	2 stations	90	12	Mattock	11	6	2.62	−0.24	Nora Springs	5.92	Sioux City	1.13
Kansas	50.6	−3.4	Coolidge	92	11	Tribune	12	9	2.59	+0.15	Yates Center	5.16	Phillipsburg	0.85
Kentucky	54.0	−1.9	Beattyville	89	20	2 stations	23	7†	2.64	−1.43	Calhoun	4.70	Lexington	1.01
Louisiana	65.1	−2.0	Angola	98	17	La Rose (near)	27	10	3.53	−0.56	New Iberia	7.30	Burrwood	1.63
Maryland-Delaware	51.4	−0.9	Cumberland, Md	89	16†	Deer Park, Md	17	7	3.00	−0.23	2 stations	3.94	Millsboro, Del	1.68
Michigan	42.4	+0.2	2 stations	80	13†	Humboldt	− 3	7	2.38	−0.02	Ironwood	5.23	Omer	0.61
Minnesota	40.5	−2.3	Lake Crystal	86	12	2 stations	−10	6	2.72	+0.74	New Richland	6.05	Hallock	1.12
Mississippi	62.4	−1.9	Anguilla	91	18	Booneville	31	9	2.95	−2.17	McNeill	7.03	Utica	1.37
Missouri	53.5	−1.8	Houston	93	23	Tarkio	21	9	3.23	−0.69	Hollister	5.65	Vandalia	1.20
Montana	42.8	+0.6	Wilder	88	27	Ovando	4	23	0.90	−0.05	Bald Butte	3.83	3 stations	T.
Nebraska	47.6	−1.6	4 stations	92	11†	Cordon	2	8	1.52	−0.88	Bradshaw	4.21	Ord	0.20
Nevada	50.4	+2.1	Logan	99	27	Wells	12	12	0.31	−0.42	Eureka	2.48	10 stations	0.00
New England	43.1	−0.5	Storrs, Conn	80	30	Van Buren, Me	12	4	3.32	+0.12	Cornish, Me	6.23	Houlton, Me	1.35
New Jersey	48.2	−0.7	Vineland	85	21	Culvers Lake	20	11	3.32	−0.19	Chatham	6.14	Pleasantville	0.90
New Mexico	50.4	−0.5	2 stations	94	25†	Tijeras Canyon	3	1	1.52	+0.47	Anchor Mine	5.88	3 stations	0.00
New York	44.1	+0.2	3 stations	80	16†	2 stations	12	7†	3.12	+0.10	Allegany	6.56	West Point	0.88
North Carolina	57.2	−0.8	Smithfield	97	13	Bannus Elk	13	10	2.31	−1.37	Belhaven	4.00	Lillington	0.84
North Dakota	39.2	−2.2	2 stations	79	27†	2 stations	− 6	6†	1.37	−0.10	Hillsboro	3.35	Lamoines	T.
Ohio	49.3	−0.6	Ironton	89	20	do	18	7	2.35	−0.76	Cadiz	4.26	Danbury	0.91
Oklahoma	56.2	−3.5	Goodwell	94	18	Goodwell	17	7	3.90	+0.87	......	......	......	......
Oregon	49.1	+0.3	Vale	86	26	Beckley	9	19	2.25	−0.10	Headworks	7.80	Owyhee	0.07
Pennsylvania	48.0	−0.5	2 stations	87	20	2 stations	16	8†	3.65	+0.24	Austin	7.40	Milford	1.65
Porto Rico	75.9	+0.6	Canovanas	97	28	Aibonito	46	6	3.65	−1.42	RioGrande(ElVerde)	10.54	Isidora	0.22
South Carolina	61.6	−0.7	5 stations	93	13	Greenville	24	10	1.79	−0.98	Bowman	3.14	Camden	0.54
South Dakota	43.6	−2.0	Fairfax	86	12	Deadwood	0	8	1.64	−0.47	Flandreau	4.26	Cedar Canyon	0.21
Tennessee	56.9	−1.3	Newport	90	20	Mountain City	16	10	2.68	−1.87	Milan	3.89	Mountain City	1.19
Texas	64.2	−1.7	3 stations	100	14†	Tulia	20	8	3.44	+0.66	Corsicana	9.58	3 stations	0.00
Utah	48.6	+1.7	Black Rock	90	25†	Scofield	0	20	0.63	−0.55	Silver Lake	5.00	do	0.00
Virginia	53.4	−0.8	Williamsburg	92	13	Burke's Station	9	10	2.45	−0.83	Gordonsville	4.65	Narrows	1.14
Washington	48.7	+0.2	Sunnyside	84	26	Wilbur	15	19	2.25	+0.15	Forks	10.64	Cowiche	0.00
West Virginia	50.5	−1.1	Romney	90	20	Green Sulphur	17	10	3.07	−0.42	Cheat Bridge	5.70	Philippi	1.80
Wisconsin	42.8	−1.0	Prairie du Chien	81	12	Deerskin Dam	1	7	2.93	+0.36	Stevens Point	5.01	Plum Island	0.65
Wyoming	40.2	+0.4	Cody	84	27	Boyd	− 9	8	0.91	−0.60	Dome Lake	3.22	Hyattville	0.03

† Other dates also.

DESCRIPTION OF TABLES AND CHARTS.

Table I gives the data ordinarily needed for climatological studies for about 158 Weather Bureau stations, making simultaneous observations at 8 a. m. and 8 p. m., daily, 75th meridian time, and for about 41 others making only one observation. The altitudes of the instruments above ground are also given.

Table II gives a record of precipitation, the intensity of which at some period of the storm's continuance equaled or exceeded the following rates:

Duration (minutes)	5	10	15	20	25	30	35	40	45	50	60
Rates per hour (inches)	3.00	1.80	1.40	1.20	1.08	1.00	0.94	0.90	0.87	0.84	0.80

It is impracticable to make this table sufficiently wide to accommodate on one line the record of accumulated falls that continue at an excessive rate for several hours. In this case *the record is broken at the end of each 50 minutes*, the accumulated amounts being recorded on successive lines until the successive rate ends.

In cases where no storm of sufficient intensity to entitle it to a place in the full table has occurred the greatest precipitation of any single storm has been given, also the greatest hourly fall during that storm.

The tipping-bucket mechanism is *dismounted* and removed when there is danger of snow or water freezing in the same. Table II records this condition by entering an asterisk (*).

Table III gives, for about 30 stations of the Canadian Meteorological Service, the means of pressure and temperature, total precipitation and depth of snowfall, and the respective departures from normal values except in the case of snowfall.

Chart I.—Hydrographs for several of the principal rivers of the United States.

Chart II.—Tracks of centers of high areas; and

Chart III.—Tracks of centers of low areas. The roman numerals show the chronological order of the centers. The figures within the circles show the days of the month; the letters *a* and *p* indicate, respectively, the observations at 8 a. m. and 8 p. m., 75th meridian time. Within each circle is also given (Chart II) the last three figures of the highest barometric reading or (Chart III) the lowest reading reported at or near the center at that time, and in both cases as reduced to sea level and standard gravity.

Chart IV.—Temperature departures. This chart presents the departures of the monthly mean temperatures from the monthly normals. The normals used in computing the departures were computed for a period of 33 years (1873 to 1905) and are published in Weather Bureau Bulletin "R," Washington, 1908. Stations whose records were too short to justify the preparation of normals in 1908 have been provided with normals as adequate records became available, and all have been reduced to the 33-year interval 1873–1905. The shaded portions of the chart indicate areas of positive departures and unshaded portions indicate areas of negative departures. Generalized lines connect places having approximately equal departures of like sign. This chart of monthly temperature departures in the United States was first published in the MONTHLY WEATHER REVIEW for July, 1909.

Chart V.—Total precipitation. The scale of shades showing the depth is given on the chart. Where the monthly amounts are too small to justify shading and over sections of the country where stations are too widely separated or the topography is to diversified to warrant reasonable accuracy in shading, the actual depths are given for a limited number of representative stations. Amounts less than 0.005 inch are indicated by the letter T, and no precipitation by 0.

Chart VI.—Percentage of clear sky between sunrise and sunset. The average cloudiness at each Weather Bureau station is determined by numerous personal observations between sunrise and sunset. The difference between the observed cloudiness and 100 is assumed to represent the percentage of clear sky, and the values thus obtained are the basis of this chart. The chart does not relate to the nighttime.

Chart VII.—Isobars and isotherms at sea level and prevailing wind directions. The pressures have been reduced to sea level and standard gravity by the method described by Prof. Frank H. Bigelow on pages 13–16 of the REVIEW for January, 1902. The pressures have also been reduced to the mean of the 24 hours by the application of a suitable correction to the mean of the 8 a. m. and 8 p. m. readings at stations taking two observations daily, and to the 8 a. m. or the 8 p. m. observation, respectively, at stations taking but a single observation. The diurnal corrections so applied will be found in the Annual Report of the Chief of the Weather Bureau, 1900–1901, volume 2, Table 27, pages 140–164.

The isotherms on the sea-level plane have been constructed by means of the data summarized in chapter 8 of volume 2 of the annual report just mentioned. The correction, t_0–t, or temperature on the sea-level plane minus the station temperature as given by Table 48 of that report, is added to the observed surface temperature to obtain the adopted sea-level temperature.

The prevailing wind directions are determined from hourly observations at the great majority of the stations; a few stations having no self-recording wind-direction apparatus determine the prevailing direction from the daily or twice-daily observations only.

Chart VIII.—Total snowfall. This is based on the reports from regular and cooperative observers and shows the depth in inches and tenths of the snowfall during the month. In general, the depth is shown by lines inclosing areas of equal snowfall, but in special cases figures are also given. Chart VIII is published only when the general snow cover is sufficiently extensive to justify its preparation.

Chart IX.—Average values of pressure, temperature, and prevailing wind directions, and storm tracks over the North Atlantic Ocean, *for the corresponding month of last year.*

TABLE I.—*Climatological data for Weather Bureau stations, April, 1916.*

Districts and stations.	Elevation of instruments.			Pressure.			Temperature of the air.												Precipitation.			Wind.									
	Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea-level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity.	Total.	Departure from normal.	Days with 0.01 or more.	Total movement.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0–10	In.	In.
New England.							43.3	− 0.4										76	3.19	− 0.1										6.6		
Eastport	76	67	85	29.81	29.89	− .04	39.8	+ 1.5	58	16	46	25	10	34	27	36	32	78	2.57	− 0.1	13	9,742	ne.	50	ne.	9	5	8	17	7.2	6.5	....
Greenville	1,070	6	....	28.74	29.92	....	39.2	....	65	17	49	17	4	29	37	....	....	....	2.45	....	10	....	se.								11.0	....
Portland, Me	103	82	117	29.80	29.93	− .03	41.8	− 1.2	59	13	48	27	10	35	23	38	32	73	5.56	+ 2.4	14	7,472	nw.	32	ne.	23	7	9	14	6.2	7.9	....
Concord	288	70	79	29.60	29.91	− .08	43.0	− 0.8	70	30	52	25	8	34	37	....	....	....	2.96	+ 0.2	15	4,544	nw.	26	e.	8	9	5	16	6.4	7.6	....
Burlington	404	11	48	29.48	29.92	− .07	43.0	+ 2.3	67	30	51	25	3	35	33	....	....	....	1.85	0.0	12	7,010	nw.	39	s.	1	4	9	17	7.1	12.3	....
Northfield	876	12	60	28.98	29.94	− .05	40.8	+ 0.6	69	30	51	20	6	30	41	37	37	73	1.94	− 0.2	12	4,770	s.	27	n.	9	4	4	22	7.6	11.3	....
Boston	125	115	188	29.77	29.91	− .06	45.6	+ 0.3	68	1	52	32	8	39	24	41	36	75	4.51	+ 1.0	14	8,221	nw.	32	nw.	18	9	7	14	6.1	4.2	....
Nantucket	12	14	90	29.87	29.88	− .09	42.8	− 1.4	57	16	48	29	1	37	19	40	37	86	2.90	+ 0.3	17	11,431	n.	50	n.	14	9	7	14	6.3	0.2	....
Block Island	26	11	46	29.87	29.90	− .08	42.4	− 1.4	56	19	47	32	8	37	17	39	37	86	3.96	+ 0.3	16	12,771	w.	48	nw.	18	10	5	15	6.4	0.4	....
Narragansett Pier	....	9	....	....	....	....	42.9	− 1.7	62	19	50	29	8	36	24	....	....	....	3.95	....	17	....	sw.	....	....	....	15	1	14	....	4.5	....
Providence	160	215	251	29.72	29.90	− .08	44.5	− 2.1	67	16	52	32	9	37	35	39	33	70	2.89	− 0.9	14	10,460	nw.	48	nw.	18	8	8	14	6.5	4.7	....
Hartford	159	122	140	29.74	29.92	− .07	45.9	− 0.8	73	30	54	31	9	38	34	40	34	69	2.93	− 0.6	13	6,134	nw.	33	nw.	18	6	7	17	7.0	3.3	....
New Haven	106	117	155	29.80	29.92	− .07	46.6	+ 0.2	67	29	54	31	9	39	25	41	37	74	3.00	− 0.6	16	7,593	n.	40	nw.	12	7	8	15	6.4	2.7	....
Middle Atlantic States.							50.4	− 0.3										68	2.44	+ 0.2										6.2		
Albany	97	102	115	29.82	29.93	− .07	45.8	0.0	76	30	54	30	3	38	34	40	34	68	3.52	+ 1.1	17	5,622	nw.	30	s.	1	10	6	14	5.7	2.1	....
Binghamton	871	10	69	28.99	29.93	− .09	45.3	+ 0.9	76	21	53	28	11	37	37	....	....	....	3.61	+ 1.4	18	2,694	nw.	26	nw.	14	3	11	16	7.1	4.0	....
New York	314	414	454	29.58	29.93	− .07	47.1	− 1.0	69	30	54	30	9	40	26	41	34	65	3.28	0.0	14	12,471	nw.	72	nw.	18	6	9	15	7.0	3.3	....
Harrisburg	374	94	104	29.56	29.96	− .06	50.4	− 0.3	75	21	59	31	8	42	29	44	38	70	2.64	+ 0.2	12	5,791	nw.	40	nw.	14	5	11	14	6.6	6.0	....
Philadelphia	117	123	190	29.82	29.95	− .06	51.4	+ 0.6	78	21	60	32	8	43	32	44	38	65	2.97	+ 0.1	12	8,371	nw.	42	nw.	14	7	8	15	6.4	5.1	....
Reading	325	81	98	29.61	29.96	....	50.0	....	77	30	59	31	8	41	31	42	34	62	3.97	+ 0.8	14	5,841	nw.	37	nw.	14	3	9	18	7.2	7.0	....
Scranton	805	111	119	29.08	29.95	− .06	47.2	+ 0.1	75	21	56	30	11	38	34	42	37	73	4.19	+ 1.5	18	5,509	ne.	37	w.	18	4	11	15	6.9	3.0	....
Atlantic City	52	37	48	29.89	29.95	− .05	47.2	− 0.4	64	14	54	33	7	41	24	42	38	74	1.85	− 1.1	13	6,221	nw.	34	nw.	14	5	8	17	6.9	0.1	....
Cape May	18	13	49	29.95	29.97	− .02	49.4	+ 1.0	67	30	56	36	9	43	23	....	....	....	1.84	− 1.2	15	7,040	nw.	50	nw.	15	8	14	8	5.5	....	....
Sandy Hook	22	10	57	29.91	29.93	....	45.8	....	63	29	51	32	9	40	20	42	39	82	3.47	....	15	11,177	nw.	59	nw.	14	6	9	15	6.5	3.4	....
Trenton	190	159	183	29.73	29.93	....	48.8	....	76	30	57	32	9	41	30	42	36	69	2.67	− 0.6	15	9,244	nw.	52	nw.	14	6	5	19	7.0	5.4	....
Baltimore	123	100	113	29.83	29.96	− .05	52.6	− 0.4	76	21	61	32	8	44	27	45	38	63	3.68	+ 0.4	12	5,821	nw.	48	nw.	14	8	10	12	6.1	5.0	....
Washington	112	62	85	29.84	29.96	− .06	53.4	+ 0.3	85	21	64	32	9	43	37	45	38	61	2.96	− 0.3	13	4,755	nw.	46	nw.	14	9	9	12	6.1	1.8	....
Lynchburg	681	153	188	29.22	29.96	− .06	54.7	− 0.9	85	20	66	31	8	43	35	47	39	62	1.94	− 1.2	12	6,137	nw.	51	nw.	14	8	16	6	5.6	1.1	....
Norfolk	91	170	205	29.87	29.96	− .05	56.4	+ 0.4	86	20	65	36	10	48	31	48	42	67	1.95	− 1.8	9	10,640	n.	62	w.	14	12	13	5	4.7	....	....
Richmond	144	11	52	29.81	29.96	− .06	55.8	− 1.4	87	20	67	33	8	45	33	48	41	64	1.94	− 1.5	8	6,776	s.	46	sw.	21	10	12	8	5.3	T.	....
Wytheville	2,293	49	55	27.60	29.98	− .05	49.5	− 2.5	79	20	59	24	10	40	38	44	39	72	1.99	− 1.7	12	5,715	w.	38	nw.	14	9	10	11	5.2	6.4	....
South Atlantic States.							61.0	− 0.2										64	1.88	− 1.6										4.3		
Asheville	2,255	70	84	27.64	29.99	− .04	52.8	− 1.1	81	13	63	26	10	43	39	45	38	63	1.35	− 2.7	12	7,085	nw.	36	e.	3	10	11	9	5.3	0.4	....
Charlotte	773	153	161	29.15	29.99	− .04	59.0	− 0.2	86	13	69	33	10	49	28	49	41	59	2.15	− 1.3	6	8,894	s.	48	nw.	23	12	11	7	4.6	T.	....
Hatteras	11	12	50	29.95	29.96	− .05	57.7	− 0.3	77	14	64	42	10	52	19	53	49	75	2.82	− 1.6	9	11,704	sw.	46	n.	6	8	16	6	5.5	....	....
Manteo	12	4	46	....	....	....	54.8	....	86	14	65	35	7	45					2.00	− 2.6	4	....	ne.				16	9	5	....	....	....
Raleigh	376	103	110	29.58	29.98	− .05	58.7	− 0.3	86	20	69	35	10	48	31	49	40	56	2.32	− 1.2	8	6,699	sw.	38	nw.	14	8	13	9	5.9	....	....
Wilmington	78	81	91	29.91	29.99	− .04	60.2	− 0.2	88	14	70	35	10	51	30	52	47	68	1.21	− 1.6	9	6,194	sw.	32	sw.	21	14	13	3	3.8	....	....
Charleston	48	11	92	29.95	30.00	− .03	64.0	+ 0.2	89	14	72	38	10	56	30	56	50	66	2.35	− 0.6	5	8,401	s.	38	s.	21	18	9	3	3.0	....	....
Columbia, S. C.	351	41	57	29.62	30.00	− .03	62.6	− 0.2	89	13	74	33	10	52	33	51	43	56	1.11	− 1.8	4	5,970	w.	34	sw.	21	14	12	4	4.2	....	....
Augusta	180	62	77	29.80	29.99	− .04	62.8	− 0.4	88	13	75	33	10	51	37	54	48	63	1.79	− 1.7	4	4,880	nw.	28	nw.	14	17	6	7	3.8	....	....
Savannah	65	150	194	29.94	30.01	− .02	65.6	+ 0.9	87	14	75	41	10	56	27	56	51	67	3.16	+ 0.2	6	9,742	s.	40	nw.	9	12	12	6	4.2	....	....
Jacksonville	43	209	245	29.97	30.02	− .02	67.0	− 0.6	87	14	76	43	10	58	30	58	52	66	0.46	− 2.3	4	9,007	sw.	40	sw.	3	18	9	3	3.0	....	....
Florida Peninsula.							71.0	− 2.4										73	1.23	− 0.7										4.0		
Key West	22	10	64	29.98	30.00	− .02	73.9	− 1.6	84	7	79	58	10	68	14	67	64	73	0.24	− 1.1	2	7,848	n.	33	n.	21	15	15	0	3.5	....	....
Miami	25	71	79	29.99	30.02	....	70.2	− 4.0	83	8	78	46	10	63	25	65	61	71	0.39	− 2.2	4	6,928	e.	27	w.	8	12	10	8	4.9	....	....
Sand Key	23	39	72	29.96	29.99	− .03	73.0	....	79	23	75	60	10	71	11	68	66	80	0.28	....	1	10,588	e.	41	n.	21	14	15	1	3.7	....	....
Tampa	35	79	96	29.99	30.03	− .03	69.0	− 1.6	87	18	79	45	10	59	28	60	55	67	3.06	+ 1.2	7	4,821	nw.	42	nw.	21	15	10	5	4.0	....	....
East Gulf States.							63.3	− 1.3										66	2.73	− 1.3										4.3		
Atlanta	1,174	190	216	28.78	30.02	− .01	60.0	− 1.1	83	13	70	34	9	50	27	50	42	58	1.51	− 2.1	7	8,812	nw.	42	se.	21	15	9	6	4.4	T.	....
Macon	370	78	87	29.61	30.01	− .02	62.6	− 0.5	87	14	75	31	10	50	36	54	47	61	1.31	− 2.1	5	4,570	nw.	24	s.	20	16	8	6	3.7	....	....
Thomasville	273	49	58	29.72	30.02	− .01	65.9	− 0.8	89	15	78	38	10	54	31	56	48	61	2.47	− 1.2	5	3,725	nw.	22	nw.	2	17	5	8	3.7	....	....
Pensacola	56	140	182	29.97	30.03	+ .01	65.4	− 2.3	83	24	72	41	9	59	22	58	53	69	4.34	+ 1.2	6	9,079	nw.	52	s.	7	14	8	8	4.6	....	....
Anniston	741	9	57	29.24	30.03	.00	59.7	− 0.7	86	15	72	32	10	47	38	....	....	....	2.71	− 0.9	7	4,373	nw.	23	s.	20	16	9	5	3.5	....	....
Birmingham	700	11	48	29.27	30.03	+ .01	61.2	− 2.3	86	15	71	34	9	51	29	52	45	62	2.14	− 1.5	7	5,042	s.	33	se.	2	13	8	9	4.8	T.	....
Mobile	57	125	161	29.96	30.02	.00	64.8	− 1.2	84	24	73	40	9	56	23	58	53	72	6.64	+ 2.3	7	7,152	nw.	36	se.	2	11	15	4	4.4	....	....
Montgomery	223	100	112	29.78	30.03	.00	63.6	− 1.6	86	15	74	37	9	53	30	54	47	60	2.23	− 2.0	8	4,792	w.	26	sw.	20	17	9	4	3.9	....	....
Meridian	375	85	93	29.62	30.01	− .01	61.9	− 2.2	85	15	73	37	10	51	34	54	48	66	2.56	− 2.5	5	4,102	sw.	26	w.	8	14	8	8	4.7	....	....
Vicksburg	247	65	74	29.75	30.03	+ .03	63.4	− 1.8	84	20	73	38	9	54	27	56	52	72	1.52	− 3.6	4	5,377	se.	31	nw.	7	9	12	9	5.3	....	....
New Orleans	51	76	84	29.96	30.02	+ .02	67.8	− 0.1	84	23	75	45	9	60	22	60	56	74	2.55	− 2.4	6	5,161	s.	29	nw.	8	12	12	6	4.1	....	....
West Gulf States.							63.5	− 2.2										71	3.63	+ 0.1										5.3		
Shreveport	249	77	93	29.74	30.01	+ .04	63.5	− 2.3	85	14	73	34	9	54	31	56	51	71	4.61	0.0	7	6,018	s.	32	w.	7	14	6	10	4.9	....	....
Bentonville	1,303	11	44	28.60	29.97	+ .01	54.9	− 2.0	79	18	64	28	9	46	31	....	....	....	6.36	+ 2.5	14	5,746	s.	30	s.	18	8	7	15	6.4	0.7	....
Fort Smith	457	79	94	29.49	29.97	+ .01	59.7	− 2.0	82	18	69	33	9	51	34	52	47	69	4.19	+ 0.3	13	7,003	e.	36	w.	20	10	6	14	5.9	T.	....
Little Rock	357	139	147	29.62	30.00	+ .02	60.6	− 2.1	83	18	70	35	9	52	31	53	46	64	2.61	− 1.9	7	8,089	s.	46	w.	15	11	8	11	5.1	....	....
Brownsville	57	3	40	....	....	....	72.5	....	95	20	83	47	9	62	33	....	....	....	1.28	....	3	....	s.	....	....	....	....	....	....	....	....	....
Corpus Christi	20	69	77	29.95	29.97	+ .02	69.6	− 1.3	84	20	75	50	9	64	24	64	61	78	0.63	− 1.2	4	11,939	se.	46	se.	13	7	12	11	5.8	....	....
Dallas	512	109	117	29.43	29.98	....	62.6	....	85	19	71	35	9	54	31	....	....	....	5.15	....	8	8,788	se.	37	se.	19	9	7	14	5.9	....	....
Fort Worth	670	106	114	29.24	29.95	+ .01	62.3	− 3.0	88	19	71	35	9	53	30	55	49	67	6.99	+ 4.3	12	8,940	s.	36	ne.	1	8	10	12	5.9	....	....
Galveston	54	106	114	29.96	30.02	+ .05	67.0	− 1.7	79	26	72	44	9	62	20	61	58	77	1.37	− 1.8	5	9,917	s.	42	s.	1	15	10	5	4.5	....	....
Houston	138	111	121	29.85	30.00	....	67.2	− 2.4	88	16	77	39	9	58	32	....	....	....	2.25	....	6	7,477	se.	34	se.	1	9	12	9	5.4	....	....
Palestine	510	64	72	29.45	29.99	+ .03	64.2	− 1.7	86	17	73	35	9	55	29	57	54	75	3.80	− 0.3	8	6,701	s.	25	sw.	23	12	5	13	4.9	....	....
San Antonio	701	109	132	29.23	29.95	+ .02	67.6	− 1.4	87	13	79	39	9	56	32	58	51	65	1.85	− 1.1	5	7,077	sw.	32	e.	30	15	11	4	3.7	....	....
Taylor	582	55	63	29.38	30.00	+ .05	65.2	− 2.3	87	22	76	34	9	54	37	....	....	....	3.87	− 0.1	6	8,751	se.	34	s.	20	9	12	9	5.1	....	....

TABLE I.—*Climatological data for Weather Bureau stations, April, 1916*—Continued.

Districts and stations.	Elevation of instruments. Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Pressure. Station, reduced to mean of 24 hours.	Sea-level, reduced to mean of 24 hours.	Departure from normal.	Temperature of the air. Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity.	Precipitation. Total.	Departure from normal.	Days with 0.01 or more.	Wind. Total movement.	Prevailing direction.	Maximum velocity. Miles per hour.	Direction.	Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
Ohio Valley and Tennessee.							**53.3**	**− 1.4**										**67**	**2.34**	**− 1.2**										**6.7**		
Chattanooga	762	189	213	29.21	30.02	− .03	59.2	− 0.8	84	20	69	33	10	49	32	50	43	61	2.55	− 1.8	12	6,707	nw.	49	nw.	20	10	11	9	5.4	T.	....
Knoxville	996	93	100	28.94	30.00	− .03	57.4	0.0	85	20	68	29	10	47	36	48	40	58	2.03	− 2.6	13	4,319	sw.	26	sw.	20	9	9	12	6.1	0.1	....
Memphis	399	76	97	29.61	30.03	+ .03	60.2	− 1.6	82	18	68	36	8	52	24	52	47	66	2.32	− 2.5	9	7,200	s.	38	nw.	8	12	7	11	5.2	T.	....
Nashville	546	168	191	29.43	30.02	+ .01	57.2	− 1.9	84	13	67	32	9	48	34	49	43	64	2.49	− 1.9	10	7,916	w.	62	w.	20	11	8	11	5.7	T.	....
Lexington	989	193	230	28.91	29.99	− .03	52.4	− 1.3	79	20	61	29	9	44	29	....	....	....	1.01	− 2.3	10	10,724	sw.	56	w.	20	6	13	11	6.1	3.1	....
Louisville	525	219	255	29.42	30.01	.00	54.0	− 2.2	81	19	62	30	9	46	31	47	42	69	3.17	− 0.9	8	10,639	sw.	52	w.	24	7	7	16	7.0	2.0	....
Evansville	431	139	175	29.53	30.00	.00	54.2	− 2.2	80	19	62	30	9	46	31	47	42	66	1.99	− 1.5	12	9,435	nw.	47	s.	19	7	13	10	6.1	1.5	....
Indianapolis	822	194	230	29.09	29.99	− .01	50.5	− 1.9	78	19	59	28	9	43	36	44	38	68	1.81	− 1.7	12	10,012	nw.	42	nw.	17	4	6	20	7.5	2.0	....
Terre Haute	575	96	129	29.35	29.98	......	51.6	......	79	19	61	28	9	43	38	45	40	69	1.39	......	11	8,529	nw.	41	se.	20	2	19	9	7.2	1.1	....
Cincinnati	628	11	51	29.29	29.98	− .03	51.6	− 2.7	80	19	61	30	9	43	33	45	39	68	2.51	− 0.4	14	6,713	sw.	36	w.	17	3	10	17	7.1	4.5	....
Columbus	824	173	222	29.09	29.97	− .05	49.9	− 1.1	79	20	58	29	7	42	30	45	41	74	2.33	− 0.5	15	8,770	nw.	51	nw.	17	9	9	12	5.9	2.0	....
Dayton	899	181	216	28.99	29.95	......	50.2	− 1.5	78	19	58	29	8	42	30	44	40	71	2.38	− 0.5	15	8,508	nw.	52	sw.	20	2	10	18	7.5	2.6	....
Pittsburgh	842	353	410	29.05	29.96	− .06	49.2	− 1.8	82	20	58	28	7	41	29	43	37	66	2.54	− 0.4	16	8,466	nw.	52	nw.	14	2	6	22	8.2	5.7	....
Elkins	1,940	41	50	27.92	29.99	− .04	48.0	− 0.7	83	20	59	23	7	37	42	42	36	70	3.43	+ 0.1	12	3,565	w.	29	w.	14	1	8	21	8.2	2.4	....
Parkersburg	638	77	84	29.33	29.99	− .04	52.5	− 0.5	86	20	61	32	7	44	32	46	40	67	2.84	− 0.1	15	4,557	nw.	39	nw.	14	7	8	15	6.6	1.0	....
Lower Lake Region.							**45.5**	**+ 0.4**										**75**	**2.34**	**0.0**										**6.5**		
Buffalo	767	247	280	29.10	29.94	− .07	42.8	+ 0.5	74	16	50	26	7	36	32	39	35	80	2.98	+ 0.5	18	11,022	w.	56	w.	14	7	9	14	6.6	0.4	....
Canton	448	10	61	29.43	29.92	......	43.8	+ 1.3	72	16	52	24	3	36	35	....	....	....	1.83	− 0.4	15	7,705	sw.	43	ne.	11	8	9	13	6.1	7.8	....
Oswego	335	76	91	29.56	29.93	− .08	42.8	− 0.4	70	16	49	29	7	36	35	39	36	80	1.58	− 0.7	19	7,202	w.	33	n.	14	4	10	16	6.8	0.3	....
Rochester	523	97	113	29.38	29.96	− .05	45.8	+ 1.9	75	16	53	28	7	38	35	40	35	70	2.37	− 0.1	15	6,331	nw.	38	w.	17	7	6	17	6.9	0.7	....
Syracuse	597	97	113	29.30	29.94	− .07	44.4	0.0	71	30	52	27	8	37	34	40	34	72	1.97	− 0.3	16	8,365	nw.	44	nw.	18	5	10	15	6.9	3.5	....
Erie	714	130	166	29.17	29.95	− .07	44.8	+ 0.1	75	20	52	28	10	38	35	41	37	78	5.26	+ 2.9	18	8,790	w.	52	w.	20	5	12	13	6.4	2.5	....
Cleveland	762	190	201	29.13	29.96	− .06	45.9	− 0.1	75	20	53	30	7	39	27	41	37	74	2.43	+ 0.1	17	8,966	w.	42	sw.	20	6	10	14	6.6	0.6	....
Sandusky	629	62	103	29.26	29.95	− .07	47.2	− 0.1	76	16	54	28	10	40	31	42	38	74	1.37	− 1.2	12	9,569	w.	48	sw.	20	3	15	12	6.9	2.0	....
Toledo	628	208	243	29.27	29.96	− .05	48.0	+ 0.7	75	20	56	28	10	40	32	42	37	69	1.30	− 1.0	14	11,515	w.	58	w.	17	10	10	10	5.8	3.8	....
Fort Wayne	856	113	124	29.04	29.97	......	48.3	+ 1.0	78	19	57	25	7	39	33	43	39	74	2.89	......	14	8,008	sw.	40	w.	17	5	12	13	6.8	2.8	....
Detroit	730	218	245	29.15	29.95	− .07	46.8	+ 1.3	76	20	55	28	10	39	34	42	37	75	2.29	0.0	16	7,317	s.	48	nw.	14	7	10	13	6.2	0.5	....
Upper Lake Region.							**41.8**	**+ 1.0**										**76**	**2.59**	**+ 0.3**										**6.3**		
Alpena	609	13	92	29.23	29.95	− .07	40.1	+ 2.1	69	29	46	22	7	34	30	37	33	79	3.01	+ 0.8	16	8,555	nw.	45	nw.	14	7	8	15	6.3	0.6	....
Escanaba	612	54	60	29.28	29.96	− .06	37.4	+ 0.2	54	17	43	15	7	32	21	34	30	79	2.34	+ 0.3	17	7,079	n.	38	nw.	17	11	3	16	6.1	0.8	....
Grand Haven	632	54	92	29.26	29.95	− .06	43.6	− 0.4	70	20	50	25	7	37	29	39	34	74	2.17	− 0.3	15	8,506	w.	33	w.	17	10	8	12	5.5	0.1	....
Grand Rapids	707	70	87	29.18	29.96	− .06	46.7	+ 0.5	73	20	56	26	9	38	28	40	34	68	2.52	+ 0.1	14	5,407	w.	36	w.	17	5	13	12	6.5	T.	....
Houghton	684	62	72	29.20	29.91	− .08	36.8	− 0.1	75	28	44	11	7	30	44	....	....	....	4.49	+ 2.5	17	6,876	w.	34	se.	20	7	10	13	6.4	4.4	....
Lansing	878	11	62	29.00	29.95	......	45.7	+ 0.1	78	20	56	23	7	36	34	40	36	75	1.91	− 0.6	16	5,783	nw.	30	nw.	14	8	9	13	6.4	0.2	....
Ludington	637	60	66	29.24	29.95	......	41.1	......	68	20	47	22	7	35	25	38	34	78	2.32	......	17	7,469	s.	37	s.	11	8	12	10	5.6	0.2	....
Marquette	734	77	111	29.17	29.98	− .04	38.4	+ 0.9	71	28	45	18	7	32	35	34	29	73	3.51	+ 1.5	17	7,299	nw.	38	nw.	17	6	7	17	7.4	1.7	....
Port Huron	638	70	120	29.25	29.95	− .07	43.4	+ 1.2	75	20	51	26	10	35	32	39	35	78	1.83	− 0.2	19	7,848	n.	48	nw.	14	9	12	9	6.0	0.8	....
Saginaw	641	48	82	29.25	29.95	......	45.5	......	73	20	54	26	7	37	30	41	36	75	1.43	− 1.3	16	7,594	nw.	37	nw.	14	6	5	19	7.4	0.2	....
Sault Ste. Marie	614	11	61	29.26	29.97	− .06	37.6	+ 1.9	66	29	45	15	7	31	38	34	30	78	3.18	+ 1.1	19	6,631	w.	39	nw.	17	8	5	17	6.8	12.1	....
Chicago	823	140	310	29.08	29.97	− .03	48.0	+ 2.1	77	12	55	26	6	41	34	42	37	71	1.60	− 1.3	10	9,854	w.	38	s.	20	8	8	14	6.2	......	....
Green Bay	617	109	144	29.26	29.93	− .08	43.0	+ 2.3	67	29	51	20	7	35	27	38	34	74	2.39	0.0	12	9,111	ne.	48	nw.	17	4	9	17	7.2	T.	....
Milwaukee	681	119	133	29.21	29.95	− .04	44.8	+ 3.0	69	20	52	23	6	37	24	40	37	80	2.66	0.0	10	8,079	w.	39	e.	19	13	6	11	5.3	......	....
Duluth	1,133	11	47	28.74	29.98	− .03	38.0	− 0.4	66	28	46	8	6	30	28	34	29	76	3.27	+ 1.1	9	11,385	ne.	53	ne.	19	8	11	11	5.7	1.4	....
North Dakota.							**39.7**	**− 1.0**										**60**	**1.52**	**− 0.4**										**5.6**		
Moorhead	940	8	57	28.99	30.03	+ .04	39.8	− 1.6	70	28	48	10	6	31	37	36	33	82	2.72	+ 0.4	12	7,296	n.	36	s.	28	12	6	12	5.2	8.4	1.5
Bismarck	1,674	8	57	28.25	30.06	+ .09	41.0	− 1.6	73	14	52	16	6	30	41	35	29	69	0.65	− 1.2	8	8,369	nw.	40	n.	7	10	10	10	4.8	0.1	....
Devils Lake	1,482	11	44	28.40	30.01	+ .02	37.8	− 0.4	70	14	47	10	5	29	35	33	28	23	1.09	− 0.9	11	9,241	nw.	34	nw.	16	7	8	15	6.4	4.3	T.
Williston	1,872	41	48	28.01	30.02	+ .06	40.3	− 0.2	75	14	50	14	5	30	39	34	27	65	1.31	+ 0.1	7	6,750	nw.	38	nw.	6	4	16	10	5.8	1.0	T.
Upper Mississippi Valley.							**49.3**	**− 1.2**										**68**	**2.46**	**− 0.5**										**4.9**		
Minneapolis	918	10	208	28.97	29.96	......	43.6	......	66	28	51	14	6	36	25	....	....	....	3.07	+ 0.6	11	9,148	n.	38	nw.	16	5	7	18	7.0	1.2	....
St. Paul	837	201	236	29.04	29.96	− .03	43.8	− 1.9	66	28	52	14	6	36	27	....	....	....	3.03	+ 0.7	10	9,968	nw.	64	e.	19	7	12	11	5.8	1.5	....
La Crosse	714	11	48	29.18	29.96	− .02	46.2	− 1.1	68	28	55	20	6	38	30	....	....	....	3.01	+ 0.7	9	4,814	s.	34	nw.	16	7	7	16	6.6	T.	....
Madison	974	70	78	28.91	29.97	− .02	45.3	+ 0.8	67	20	54	19	6	37	21	39	34	70	3.51	+ 1.1	11	8,259	nw.	36	n.	8	7	6	17	6.9	T.	....
Charles City	1,015	10	49	28.89	29.98	.00	44.6	− 1.7	81	12	54	15	6	35	31	40	36	75	3.69	+ 0.9	13	5,906	nw.	30	sw.	12	6	12	12	6.5	0.5	....
Davenport	606	71	79	29.30	29.96	− .02	49.4	− 0.8	79	12	58	23	6	40	29	43	37	67	2.45	− 0.4	13	6,187	nw.	36	sw.	19	4	10	16	7.1	T.	....
Des Moines	861	84	97	29.06	29.97	.00	48.6	− 2.0	87	12	58	21	6	39	31	43	37	67	2.44	− 0.5	12	6,320	n.	38	sw.	12	4	11	15	7.1	1.4	....
Dubuque	698	81	96	29.23	29.99	+ .01	48.2	− 0.7	82	12	57	22	6	39	31	41	34	64	2.69	− 0.2	10	5,859	nw.	27	sw.	19	9	6	15	6.5	T.	....
Keokuk	614	64	78	29.30	29.98	.00	50.8	− 1.2	80	12	60	25	6	42	29	45	40	69	2.44	− 0.9	13	6,184	nw.	46	sw.	19	12	11	7	4.9	T.	....
Cairo	356	87	93	29.60	29.99	.00	56.5	− 1.8	78	19	64	34	8	49	29	50	44	68	1.66	− 1.9	9	8,291	s.	34	s.	19	9	8	13	6.1	T.	....
Peoria	609	11	45	29.32	29.98	− .01	49.8	− 1.1	82	12	59	24	9	40	29	44	38	68	1.60	− 1.7	11	6,394	s.	37	w.	20	8	12	10	5.6	......	....
Springfield, Ill	644	10	91	29.29	29.98	.00	51.6	− 0.4	84	12	61	27	6	42	36	45	39	67	1.43	− 1.9	14	7,097	nw.	34	sw.	20	4	7	19	7.2	0.6	....
Hannibal	534	74	109	29.40	29.98	.00	51.8	− 1.8	84	12	61	28	6	43	31	....	....	....	1.64	− 1.6	16	7,531	sw.	38	w.	19	8	9	13	6.1	T.	....
St. Louis	567	265	303	29.37	29.98	.00	54.4	− 1.7	85	12	63	30	6	46	32	47	42	67	1.78	− 1.7	13	10,508	nw.	49	sw.	19	8	9	13	5.8	0.5	....
Missouri Valley.							**48.8**	**− 1.6**										**63**	**2.35**	**− 0.5**										**6.3**		
Columbia, Mo	781	11	84	29.14	29.98	.00	53.0	− 1.3	84	12	62	30	9	44	32	....	....	....	2.68	− 1.0	14	6,650	nw.	38	w.	19	5	8	17	7.3	1.0	....
Kansas City	963	161	181	28.95	29.99	+ .03	52.6	− 1.7	80	11	61	30	7	45	29	46	41	68	4.16	+ 0.9	11	8,960	n.	43	nw.	21	7	11	12	6.1	4.1	....
St. Joseph	967	11	49	28.94	29.99	......	51.8	......	85	12	62	28	9	42	31	44	38	66	2.96	......	10	6,945	nw.	39	nw.	21	8	9	13	6.3	1.4	....
Springfield, Mo	1,324	98	104	28.58	29.99	+ .02	52.8	− 2.9	80	18	61	28	9	44	29	46	42	72	5.15	+ 1.3	14	8,600	s.	40	sw.	19	12	10	8	4.8	5.2	....
Iola	984	11	50	28.92	29.98	+ .03	52.6	− 1.6	80	22	62	28	9	44	37	....	....	....	3.83	+ 1.0	11	6,685	ne.	30	s.	19	7	13	10	5.8	6.7	....
Topeka	983	85	101	......	......	......	52.0	− 1.7	82	12	61	27	9	43	36	....	....	....	2.26	− 0.5	11	8,114	nw.	46	w.	19	5	13	12	6.5	1.7	....
Drexel	1,299	10	53	28.60	30.01	......	47.4	......	85	12	58	22	6	37	39	42	37	73	1.79	......	9	8,483	nw.	39	s.	12	4	10	16	7.3	4.7	....
Lincoln	1,189	11	84	28.71	29.99	+ .05	49.2	− 1.5	86	11	60	24	9	39	44	42	36	66	2.69	− 0.1	10	7,744	n.	40	nw.	20	5	12	13	6.8	2.4	....
Omaha	1,105	115	121	28.80	30.00	+ .05	49.5	− 1.0	86	12	59	24	6	40	38	43	36	66	1.72	− 1.3	11	6,817	nw.	38	nw.	21	6	12	12	6.5	0.4	....
Valentine	2,598	47	54	27.28	30.02	+ .08	44.2	− 1.2	81	11	56	17	8	33	42	39	35	74	0.59	− 1.7	9	7,813	nw.	39	sw.	28	8	10	12	5.9	1.5	....
Sioux City	1,135	94	164	28.77	30.00	+ .05	47.0	− 1.5	82	12	56	19	6	38	39	41	34	67	1.12	− 1.6	11	9,699	nw.	48	nw.	16	8	13	9	5.4	3.1	....
Huron	1,306	59	74	28.62	30.04	+ .08	43.4	− 1.2	73	12	54	14	6	33	40	38	32	72	1.16	− 1.5	10	9,216	nw.	41	s.	28	4	12	14	6.7	1.4	....
Pierre	1,572	70	75	28.35	30.03	+ .08	44.6	− 1.9	73	14	56	17	6	34	44	38	30	63	1.06	− 0.9	13	7,942	nw.	42	nw.	7	6	10	14	6.2	2.2	....
Yankton	1,233	49	57	28.66	29.99	+ .04	46.2	− 1.2	81	12	56	19	6	37	38	....	....	....	1.74	− 1.1	11	7,105	nw.	34	s.	28	5	11	14	6.8	1.6	....

TABLE I.—*Climatological data for Weather Bureau stations, April, 1916*—Continued.

Districts and stations.	Elevation of instruments: Barometer above sea level.	Elevation of instruments: Thermometer above ground.	Elevation of instruments: Anemometer above ground.	Pressure: Station, reduced to mean of 24 hours.	Pressure: Sea-level, reduced to mean of 24 hours.	Pressure: Departure from normal.	Temperature of the air: Mean max.+mean min.÷2.	Temperature of the air: Departure from normal.	Temperature of the air: Maximum.	Temperature of the air: Date.	Temperature of the air: Mean maximum.	Temperature of the air: Minimum.	Temperature of the air: Date.	Temperature of the air: Mean minimum.	Temperature of the air: Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity.	Precipitation: Total.	Precipitation: Departure from normal.	Precipitation: Days with 0.01 or more.	Wind: Total movement.	Wind: Prevailing direction.	Wind: Maximum velocity: Miles per hour.	Wind: Maximum velocity: Direction.	Wind: Maximum velocity: Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
Northern Slope.							**43.4**	**+ 0.6**										**61**	**0.82**	**− 0.8**										**4.5**		
Havre	2,505	11	44	27.35	30.00	+ .07	43.8	+ 1.1	84	27	57	17	7	30	51	37	29	63	0.69	− 0.3	6	6,485	sw.	42	w.	21	12	15	3	4.5	0.1	....
Helena	4,110	87	114	25.80	30.02	+ .05	44.2	+ 2.2	76	27	55	25	30	33	37	36	26	54	1.65	+ 0.5	9	7,158	sw.	39	sw.	21	7	15	8	5.5	9.7	....
Kalispell	2,962	11	34	26.95	30.03	+ .07	43.5	+ 1.0	77	26	55	26	30	32	42	36	29	64	0.73	− 0.3	8	3,852	w.	26	w.	27	7	15	8	5.8	T.	....
Miles City	2,371	26	48	27.49	30.06	+ .10	46.2	+ 1.5	82	27	59	18	8	33	45	38	31	62	0.22	− 1.0	4	4,982	n.	30	nw.	12	13	11	6	4.3	1.3	....
Rapid City	3,259	50	58	26.60	30.06	+ .11	42.8	− 0.7	70	11	53	12	8	33	39	36	28	58	1.24	− 1.1	11	7,367	n.	44	n.	20	8	9	13	5.9	1.9	....
Cheyenne	6,088	84	101	23.96	29.98	+ .07	40.2	− 1.4	73	28	52	12	8	29	40	33	27	64	0.48	− 1.4	8	9,213	n.	42	n.	7	3	12	15	6.9	2.4	....
Lander	5,372	60	68	24.61	29.99	+ .05	43.5	+ 1.3	76	27	57	17	6	30	43	35	24	54	0.62	− 1.8	6	4,358	w.	48	sw.	28	8	16	6	5.4	3.0	....
Sheridan	3,790	10	47	26.11	30.04	......	43.2	......	77	27	55	20	8	31	47	36	29	64	2.71	......	12	4,962	nw.	35	nw.	6	8	9	13	5.8	7.3	....
Yellowstone Park	6,200	11	48	23.84	30.00	+ .04	38.4	+ 1.4	66	26	50	17	4	27	38	31	24	60	1.05	− 0.3	10	5,644	nw.	38	s.	17	9	10	11	5.6	5.9	....
North Platte	2,821	11	51	27.08	30.02	+ .10	47.8	− 1.2	87	11	61	19	8	35	44	40	33	63	0.72	− 1.4	7	5,935	n.	39	n.	7	9	12	9	5.4	0.3	....
Middle Slope.							**50.5**	**− 3.2**										**66**	**2.60**	**− 0.4**										**6.1**		
Denver	5,292	106	113	24.69	29.97	+ .07	46.4	− 1.3	80	28	58	19	8	35	34	37	28	58	1.93	− 0.2	9	5,393	se.	40	n.	12	4	15	11	6.2	11.5	1.0
Pueblo	4,685	80	86	25.26	29.95	+ .07	48.6	− 1.9	84	28	62	22	8	35	48	38	29	57	2.02	+ 0.6	10	4,740	se.	39	w.	18	6	17	7	5.7	6.7	T.
Concordia	1,392	50	58	28.52	30.01	+ .08	50.2	− 3.4	85	11	61	24	9	40	42	43	36	66	1.82	− 0.6	9	7,146	nw.	37	nw.	7	1	14	15	7.4	0.9	....
Dodge	2,509	11	51	27.39	30.01	+ .11	50.2	− 4.2	88	11	62	22	8	38	42	42	37	70	2.84	+ 1.0	9	8,570	nw.	43	nw.	19	10	11	9	5.5	4.9	....
Wichita	1,358	139	158	28.52	29.96	+ .06	52.2	− 4.4	80	19	61	28	9	44	32	46	41	70	3.87	+ 1.2	9	10,969	ne.	48	nw.	19	11	4	15	6.0	5.3	....
Oklahoma	1,214	10	47	28.69	29.98	+ .06	55.4	− 4.2	84	19	65	27	9	46	29	49	45	74	3.15	+ 0.4	9	12,239	s.	50	s.	29	6	14	10	5.6	......	....
Southern Slope.							**60.2**	**− 2.2**										**48**	**2.31**	**+ 0.4**										**4.3**		
Abilene	1,738	10	52	28.14	29.94	+ .04	61.6	− 2.8	92	23	73	33	9	50	37	51	43	60	5.13	+ 2.8	7	9,066	s.	38	nw.	25	12	8	10	5.2	......	....
Amarillo	3,676	10	49	26.23	29.96	+ .09	52.9	− 1.7	87	11	66	26	8	40	47	43	36	64	1.71	0.0	8	9,123	ne.	42	ne.	7	18	7	5	4.1	T.	....
Del Rio	944	64	71	28.95	29.93	+ .04	69.2	− 0.8	92	16	81	43	2	58	36	......	......	......	0.29	− 1.6	3	8,719	se.	42	n.	26	12	12	6	4.2	......	....
Roswell	3,566	75	85	26.32	29.91	+ .06	57.2	− 3.4	86	29	72	25	8	42	45	43	26	39	1.11	+ 0.6	6	6,789	s.	40	nw.	15	17	6	7	3.6	......	....
Southern Plateau.							**58.6**	**+ 0.8**										**40**	**0.52**	**0.0**										**2.6**		
El Paso	3,762	110	133	26.13	29.86	+ .03	62.7	− 1.1	88	17	76	34	1	50	35	46	25	31	0.20	0.0	1	9,193	w.	49	ne.	30	19	10	1	2.5	......	....
Santa Fe	7,013	57	66	23.20	29.90	+ .06	46.6	− 1.0	72	28	58	21	8	35	34	36	26	53	2.50	+ 1.6	7	5,965	e.	40	sw.	19	9	15	6	4.8	13.2	....
Flagstaff	6,908	8	57	23.31	29.88	+ .04	44.2	+ 2.0	74	27	60	17	8	29	45	......	......	......	0.06	− 1.6	3	......	w.	45	w.	29	20	9	1	....	0.2	....
Phoenix	1,108	76	81	28.72	29.86	− .01	68.2	+ 1.6	95	25	83	44	1	54	41	52	36	37	0.15	− 0.3	1	3,970	e.	23	se.	11	20	9	1	2.4	......	....
Yuma	141	9	54	29.71	29.86	− .03	73.0	+ 2.9	101	27	90	47	1	56	40	56	41	39	0.01	− 0.1	1	4,177	w.	28	n.	30	28	2	0	0.6	......	....
Independence	3,910	11	42	25.94	29.90	.00	56.9	+ 0.2	84	28	74	33	8	40	41	......	......	......	0.21	+ 0.1	1	5,471	n.	30	w.	17	23	6	1	......	......	....
Middle Plateau.							**50.3**	**+ 1.4**										**42**	**0.38**	**− 0.8**												
Reno	4,532	74	81	25.49	30.01	+ .04	50.1	+ 2.8	75	25	64	28	12	36	39	38	26	44	0.11	− 0.5	2	5,818	w.	33	w.	18	22	6	2	4.6	T.	....
Tonopah	6,090	12	20	24.05	29.94	......	49.9	......	73	27	61	26	12	39	27	37	32	38	0.66	− 1.0	2	6,986	nw.	34	nw.	5	13	14	3	3.7	5.0	....
Winnemucca	4,344	18	56	25.62	30.01	+ .05	49.0	+ 1.9	80	26	65	24	19	33	48	37	24	46	0.19	− 0.7	3	5,155	sw.	34	sw.	21	17	4	9	4.2	......	....
Modena	5,479	10	43	24.58	29.91	+ .03	48.2	+ 1.3	78	27	64	21	30	32	44	35	18	38	0.23	− 0.6	3	8,556	w.	45	s.	11	17	10	3	3.4	......	....
Salt Lake City	4,360	147	189	25.58	29.94	+ .02	51.6	+ 1.5	81	27	61	31	19	42	29	41	30	45	0.88	− 1.4	7	6,208	nw.	39	nw.	11	7	14	9	5.3	0.6	....
Grand Junction	4,602	82	96	25.33	29.90	+ .02	52.7	− 0.5	82	28	66	7	20	40	36	40	26	42	0.20	− 0.6	4	5,323	se.	37	w.	18	9	13	8	5.4	0.9	....
Northern Plateau.							**49.8**	**+ 0.8**										**53**	**0.97**	**− 0.4**										**5.4**		
Baker	3,471	48	53	26.48	30.08	+ 0.8	45.5	+ 2.0	77	26	58	23	19	34	39	59	31	62	0.85	− 0.1	8	4,794	se.	27	se.	20	17	6	7	3.9	T.	....
Boise	2,739	78	86	27.18	30.05	+ .07	51.4	+ 1.3	83	26	64	29	5	39	36	41	29	46	0.80	− 0.4	5	4,583	nw.	30	nw.	4	11	6	13	5.6	......	....
Lewiston	757	40	48	29.26	30.08	+ .09	52.2	− 0.7	82	26	64	33	16	40	42	......	......	......	0.84	− 0.3	10	2,771	e.	26	w.	4	8	10	12	6.0	......	....
Pocatello	4,477	46	54	25.45	29.97	+ .03	48.0	+ 1.2	76	25	60	26	3	36	34	38	26	47	0.36	− 1.7	4	6,962	sw.	38	sw.	19	8	13	9	5.4	0.1	....
Spokane	1,929	109	110	28.00	30.07	+ .08	48.4	+ 0.7	80	26	59	31	16	38	37	41	32	58	1.16	− 0.1	9	5,083	sw.	30	sw.	21	4	11	15	6.8	3.9	....
Walla Walla	991	57	65	28.97	30.05	+ .04	53.1	+ 0.3	78	26	63	36	12	43	31	45	35	54	1.83	+ 0.1	9	4,288	s.	22	sw.	4	13	11	6	4.5	......	....
North Pacific Coast Region.							**49.6**	**+ 0.5**										**77**	**3.33**	**− 0.1**										**6.6**		
North Head	211	11	56	29.91	30.14	+ .09	46.8	− 0.7	56	25	50	39	18	44	9	45	43	86	3.32	+ 0.1	19	12,212	nw.	70	se.	26	4	7	19	7.2	......	....
Seattle	125	215	250	30.01	30.14	+ .11	49.0	− 0.4	66	26	56	38	22	42	25	44	39	72	1.98	− 0.7	16	7,195	s.	40	sw.	21	3	10	17	7.2	......	....
Tacoma	213	113	120	29.91	30.14	+ .11	49.2	+ 0.3	68	26	57	34	16	41	27	44	40	73	2.86	+ 0.1	17	4,740	sw.	29	sw.	18	3	12	15	7.0	......	....
Tatoosh Island	109	7	57	30.00	30.10	+ .10	46.2	+ 0.1	55	2	50	38	21	42	14	44	42	89	6.70	+ 0.4	22	10,865	s.	49	s.	18	4	8	18	7.0	......	....
Portland, Oreg.	153	68	106	29.97	30.13	+ .07	53.0	+ 1.8	73	7	62	36	12	44	29	46	39	63	2.85	− 0.2	18	4,466	w.	31	w.	18	4	13	13	6.5	......	....
Roseburg	510	9	57	29.60	30.16	+ .09	52.6	+ 1.7	80	13	66	32	12	40	43	45	38	65	2.28	− 0.2	12	2,343	nw.	23	sw.	26	10	18	2	4.4	......	....
Middle Pacific Coast Region.							**56.3**	**+ 2.7**										**63**	**0.36**	**− 1.7**										**2.6**		
Eureka	62	73	89	30.10	30.17	+ .06	50.2	+ 0.7	70	26	56	38	12	44	26	47	45	87	1.98	− 2.0	9	6,058	n.	36	n.	1	10	13	7	5.1	......	....
Mt. Tamalpais	2,375	11	18	27.60	30.08	+ .03	53.3	+ 3.8	75	30	61	36	11	45	25	44	34	52	0.05	− 1.4	3	16,483	nw.	84	nw.	10	23	7	0	1.8	......	....
Point Reyes Light	490	7	18	29.52	30.04	......	51.6	+ 3.0	65	27	56	44	9	47	17	......	......	......	0.01	......	1	18,426	nw.	87	nw.	11	14	12	4	4.0	......	....
Red Bluff	332	50	56	29.68	30.03	.00	62.5	+ 3.4	87	30	75	42	19	50	32	50	37	45	0.04	− 1.8	2	4,720	nw.	30	nw.	29	20	8	2	2.5	......	....
Sacramento	69	106	117	29.96	30.03	+ .02	61.0	+ 3.0	85	30	74	41	18	48	33	52	44	61	0.06	− 1.9	2	6,324	s.	37	nw.	29	27	3	0	1.2	......	....
San Francisco	155	209	213	29.91	30.08	+ .03	57.6	+ 3.9	83	30	65	46	9	50	27	51	46	72	0.00	− 1.8	0	6,914	sw.	31	sw.	13	22	8	0	1.8	......	....
San Jose	141	12	110	29.92	30.07	......	57.6	+ 0.9	85	30	71	36	16	44	41	......	......	......	0.06	− 1.4	1	3,970	nw.	24	w.	11	28	2	0	1.5	......	....
South Pacific Coast Region.							**61.0**	**+ 3.0**										**69**	**0.06**	**− 1.0**										**2.5**		
Fresno	327	89	98	29.66	30.02	+ .03	62.4	+ 1.2	84	10	76	42	18	48	39	52	42	55	0.02	− 0.7	1	6,521	nw.	28	nw.	10	22	8	0	1.7	......	....
Los Angeles	338	159	191	29.62	29.98	− .01	62.4	+ 4.8	84	7	72	49	12	53	31	54	49	70	T.	− 1.1	0	3,937	sw.	16	s.	18	20	6	4	3.0	......	....
San Diego	87	62	70	29.89	29.98	− .01	60.2	+ 2.0	79	7	67	48	7	54	31	55	51	78	0.01	− 0.7	1	4,341	nw.	22	w.	11	21	6	3	3.0	......	....
San Luis Obispo	201	32	40	29.85	30.07	+ .02	59.0	+ 3.8	86	20	72	37	13	46	40	51	46	72	0.21	− 1.3	3	3,470	nw.	18	w.	17	23	4	3	2.3	......	....
West Indies.																																
San Juan	82	8	54	29.90	29.99	+ .01	76.6	......	90	26	82	65	3	71	18	......	......	......	3.61	− 0.2	9	9,316	ne.	32	e.	9	10	17	3	4.3	......	....
Panama.																																
Balboa Heights	118	7	97	29.73	29.85	......	81.2	......	92	5	89	69	1	74	20	74	73	83	2.84	0.0	14	5,432	nw.	27	n.	10	4	10	16	6.9	......	....
Colon	25	5	71	29.84	29.86	......	81.8	......	89	27	86	73	1	77	14	77	76	84	6.25	+ 2.0	12	8,424	n.	31	ne.	12	4	18	8	6.0	......	....

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during April, 1916, at all stations furnished with self-registering gages.*

Stations.	Date.	Total duration. From—	Total duration. To—	Total amount of precipitation.	Excessive rate. Began—	Excessive rate. Ended—	Amount before excessive rate began.	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Abilene, Tex	25–26			1.60														*			
Albany, N. Y	22–24			0.85														0.25			
Alpena, Mich	19–20			1.05														.29			
Amarillo, Tex	14			0.97														.16			
Anniston, Ala	20			0.41														.37			
Asheville, N. C	2–3			0.65														.16			
Atlanta, Ga	16			0.23														.21			
Atlantic City, N. J	8–9			0.60														*			
Augusta, Ga	29	12:15 p. m.	2:05 p. m.	0.65	12:49 p. m.	1:08 p. m.	0.02	0.11	0.27	0.42	0.53										
Baker, Oreg	17			0.17														.14			
Baltimore, Md	8–9			1.86														.25			
Bentonville, Ark	20			1.05														.57			
Binghamton, N. Y	14			0.77														.21			
Birmingham, Ala	20			0.42														.38			
Bismarck, N. Dak	19			0.43														.34			
Block Island, R. I	22			0.71														.28			
Boise, Idaho	18			0.38														*			
Boston, Mass	22–24			1.55														.28			
Buffalo, N. Y	12–13			0.92														*			
Burlington, Vt	22–24			0.56														*			
Cairo, Ill	20			1.05														.29			
Canton, N. Y	22–23			0.58														.16			
Charles City, Iowa	18–20			1.12														*			
Charleston, S. C	3	d. n. a. m.	d. n. a. m.	1.28	2:27 a. m.	3:04 a. m.	.02	.07	.11	.28	.42	0.55	0.69	0.77	0.81						
Charlotte, N. C	5			0.74														.35			
Chattanooga, Tenn	16	1:48 p. m.	5:02 p. m.	0.47	2:15 p. m.	2:25 p. m.	.01	.23	.34												
Cheyenne, Wyo	12			0.17														*			
Chicago, Ill	18–19			0.52														.23			
Cincinnati, Ohio	20	6:53 p. m.	9:50 p. m.	0.57	7:09 p. m.	7:15 p. m.	.01	.29	.31												
Cleveland, Ohio	16			0.47														.36			
Columbia, Mo	30			0.60														.26			
Columbia, S. C	3			0.54														.31			
Columbus, Ohio	26–27			0.96														.16			
Concord, N. H	22–24			1.22														.14			
Concordia, Kans	19–20			0.51														.26			
Corpus Christi, Tex	24			0.35														.34			
Davenport, Iowa	19–20			0.47														.31			
Dayton, Ohio	20			0.92														.32			
Del Rio, Tex	26			0.20														*			
Denver, Colo	29–30			0.82														*			
Des Moines, Iowa	29–30			1.21														*			
Detroit, Mich	13	4:55 p. m.	7:10 p. m.	0.41	6:34 p. m.	6:44 p. m.	.03	.16	.36												
Devils Lake, N. Dak	18–19			0.51														.10			
Dodge City, Kans	4–5			1.29														*			
Dubuque, Iowa	19	5:42 p. m.	7:05 p. m.	0.48	6:10 p. m.	6:17 p. m.	.01	.34	.39												
Duluth, Minn	19–21			2.04														.23			
Durango, Colo																					
Eastport, Me	18			0.71														.26			
Elkins, W. Va	24–25			0.90														*			
El Paso, Tex	1			0.20														.06			
Erie, Pa	20	5:49 p. m.	6:45 p. m.	0.50	5:49 p. m.	6:00 p. m.	.00	.20	.44	.47											
Escanaba, Mich	19–23			1.56														.18			
Eureka, Cal	21			0.37														.17			
Evansville, Ind	20			1.08														.45			
Flagstaff, Ariz	13			0.03														*			
Fort Smith, Ark	20	D. N. a. m.	8:50 a. m.	0.90	5:41 a. m.	6:22 a. m.	.01	.17	.20	.27	.36	.48	.54	.64	.68						
Fort Wayne, Ind	25–27			1.36														.18			
Fort Worth, Tex	23	7:10 p. m.	11:10 p. m.	0.37	8:06 p. m.	8:16 p. m.	.02	.21	.30												
Fresno, Cal	11			0.02														.01			
Galveston, Tex	1			0.99														.49			
Grand Haven, Mich	16			0.31														.23			
Grand Junction, Colo	19			0.13														.07			
Grand Rapids, Mich	19			0.59														.25			
Green Bay, Wis	19	8:45 p. m.	11:15 p. m.	0.66	10:35 p. m.	10:50 p. m.	.16	.23	.34	.46											
Hannibal, Mo	19–21			0.42														.25			
Harrisburg, Pa	21–22			0.99														*			
Hartford, Conn	8–9			1.04														*			
Hatteras, N. C	26	8:33 p. m.	9:40 p. m.	0.80	8:40 p. m.	8:54 p. m.	.02	.28	.48	.54											
Havre, Mont	11			0.55														.20			
Helena, Mont	4–5			0.77														*			
Houghton, Mich	19–23			3.19														*			
Houston, Tex	1	11:43 a. m.	3:15 p. m.	0.86	2:39 p. m.	2:59 p. m.	.17	.15	.44	.56	.67										
Huron, S. Dak	18			0.16														*			
Independence, Cal	11			0.21														.17			
Indianapolis, Ind	20			0.88														.27			
Iola, Kans	13			0.58														.36			
Jacksonville, Fla	2–3			0.27														.15			
Kalispell, Mont	29			0.26														*			
Kansas City, Mo	30			2.32														*			
Keokuk, Iowa	30			0.60														*			
Key West, Fla	3			0.21														.08			
Knoxville, Tenn	7–8			0.72														*			
La Crosse, Wis	18–19			1.28														.36			
Lander, Wyo	2			0.24														*			
Lansing, Mich	13–14			0.48														.28			
La Salle, Ill																					
Lewiston, Idaho	4–5			0.25														.11			
Lexington, Ky	16			0.20														.19			
Lincoln, Nebr	19–20	6:52 p. m.	9:25 a. m.	1.83	7:11 p. m.	7:41 p. m.	.02	.09	.30	.60	.82	.91	.97								
Little Rock, Ark	20			0.69														.60			
Los Angeles, Cal	4,10,11			T.														T.			
Louisville, Ky	20	9:34 a. m.	D.N.p. m.	1.63	3:28 p. m.	8:43 p. m.	.20	.07	.20	.35											
Ludington, Mich	19–21			0.66														.21			
Lynchburg, Va	5–6			0.66														.23			
Macon, Ga	21			0.31														.22			
Madison, Wis	18–20			1.57														.26			
Marquette, Mich	19–21			1.63														.29			
Memphis, Tenn	20			0.70														.45			

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during April, 1916, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration. From—	Total duration. To—	Total amount of precipitation.	Excessive rate. Began—	Excessive rate. Ended—	Amount before excessive rate began.	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Meridian, Miss	16	10:07 a. m.	2:30 p. m.	0.80	10:16 a. m.	10:31 a. m.	0.07	0.20	0.43	0.51											
Miami, Fla	28			0.24														0.23			
Milwaukee, Wis	18-21			0.86														.23			
Minneapolis, Minn	29			0.53														.22			
Mobile, Ala	2	6:47 a. m.	9:10 a. m.	1.18	7:27 a. m.	8:09 a. m.	.02	.06	.17	.23	0.36	0.49	0.76	1.01	1.10	1.14					
	20-21	3:10 p. m.	D.N.a.m.	3.73	12:17 a. m.	12:52 a. m.	2.07	.12	.38	.69	.97	1.17	1.37	1.48							
Modena, Utah	12			0.08														.08			
Montgomery, Ala	2-3			0.98														.51			
Moorhead, Minn	19-21			1.25														.14			
Mount Tamalpais, Cal	10-11			0.04														.01			
Mount Weather, Va																					
Nantucket, Mass	14-15			0.82														.19			
Nashville, Tenn	20	4:30 p. m.	8:40 p. m.	1.40	4:40 p. m.	4:58 p. m.	.01	.10	.34	.44	.50										
New Haven, Conn	14-15			0.98														*			
New Orleans, La	16	11:45 a. m.	3:30 p. m.	1.03	12:35 p. m.	12:50 p. m.	.14	.10	.25	.38											
New York, N. Y	14			1.37														.29			
Norfolk, Va	5-6			1.17														.25			
Northfield, Vt	22-23			0.79														*			
North Head, Wash	19			0.87														.23			
North Platte, Nebr	23			0.42														.12			
Oklahoma, Okla	13-14			0.90														*			
Omaha, Nebr	18	4:10 a. m.	5:30 a. m.	1.10	4:28 a. m.	5:13 a. m.	.05	.08	.20	.38	.52	.59	.63	.86	.96	1.03					
Oswego, N. Y	20-25			0.62														*			
Palestine, Tex	1	7:02 a. m.	1:35 p. m.	0.96	7:46 a. m.	7:52 a. m.	.12	.27	.29												
Parkersburg, W. Va	21	12:58 p. m.	5:20 p. m.	1.27	1:27 p. m.	1:53 p. m.	.09	.27	.37	.53	.76	.92	.96								
	2	8:25 a. m.	12 noon.	1.27	9:59 a. m.	10:30 a. m.	.06	.19	.33	.41	.54	.64	.67								
Pensacola, Fla	20-21	9:15 p. m.	3:15 a. m.	2.12	9:29 p. m.	10:05 p. m.	.10	.21	.38	.66	.78	.86	.96	1.00							
					12:56 a. m.	1:27 a. m.	.06	.17	.21	.34	.40	.51	.56								
Peoria, Ill	1			0.32														.18			
Philadelphia, Pa	8-9			1.15														*			
Phoenix, Ariz	13			0.15														.05			
Pierre, S. Dak	15-16			0.25														.10			
Pittsburgh, Pa	8-9			0.57														*			
Pocatello, Idaho	11			0.19														.15			
Point Reyes Light, Cal	20			0.01														.01			
Port Huron, Mich	12			0.26														.16			
Portland, Me	22-24			1.77														.15			
Portland, Oreg	19-21			0.76														.17			
Providence, R. I	27-28			0.83														*			
Pueblo, Colo	29-30			1.16														*			
Raleigh, N. C	5			0.76														.35			
Rapid City, S. Dak	18-19			0.60														.50			
Reading, Pa	21	5:45 p. m.	6:33 p. m.	0.75	5:57 p. m.	6:20 p. m.	.05	.05	.19	.35	.63	.68									
Red Bluff, Cal	10			0.02														.02			
Reno, Nev	1			0.10														.04			
Richmond, Va	5-6			0.61														.23			
Rochester, N. Y	21-24			1.21														*			
Roseburg, Oreg	9-11			1.23														.16			
Roswell, N. Mex	13			0.36														.15			
Sacramento, Cal	11			0.03														.03			
Saginaw, Mich	19			0.34														.24			
St. Joseph, Mo	18			0.54														.46			
St. Louis, Mo	14-16			.51														.31			
St. Paul, Minn	20			0.65														.23			
Salt Lake City, Utah	18			0.28														.15			
San Antonio, Tex	15			1.11														.47			
San Diego, Cal	12			0.01														.01			
Sand Key, Fla	3			0.28														.14			
Sandusky, Ohio	20			0.22														.16			
San Francisco, Cal	‡																				
San Jose, Cal	10			0.06														.05			
San Luis Obispo, Cal	10-11			0.20														.08			
Santa Fe, N. Mex	26			0.47														.21			
Sault Ste. Marie, Mich	20-21			0.72														*			
Savannah, Ga	3			1.49														*			
Scranton, Pa	13			0.60														.24			
Seattle, Wash	26-28			0.79														.23			
Sheridan, Wyo	15			0.35														.20			
Shreveport, La	1			2.29														.67			
Sioux City, Iowa	19			0.22														.21			
Southeast Farallone, Cal																					
Spokane, Wash	20-21			0.54														.08			
Springfield, Ill	20			0.44														.28			
Springfield, Mo	20	D. N. a. m.	10:20 a. m.	1.24	1:59 a. m.	2:08 a. m.	.13	.31	.36												
Syracuse, N. Y	22-24			0.67														*			
Tacoma, Wash	26-28			1.06														.20			
Tampa, Fla	17	3:13 p. m.	4:18 p. m.	0.78	3:22 p. m.	4:08 p. m.	.01	.16	.28	.31	.33	.37	.44	.55	.64	.72	.76				
Tatoosh Island, Wash	11-15			1.80														.24			
Taylor, Tex	1	7:54 a. m.	9:52 a. m.	2.24	7:57 a. m.	9:15 a. m.	.01	.07	.48	.82	.92	1.06	1.08	1.10	1.22	1.33	1.42	1.82	2.15		
Terre Haute, Ind	16			0.24														.15			
Thomasville, Ga	2-3	3:20 p. m.	D. N. a. m.	1.73	3:55 p. m.	4:12 p. m.	.08	.13	.29	.38	.43										
Toledo, Ohio	8			0.42														*			
Tonopah, Nev	11			0.64														*			
Topeka, Kans	30			0.94														.25			
Valentine, Nebr	23			0.22														.14			
Vicksburg, Miss	1-2			0.76														.46			
Walla Walla, Wash	10-11			1.03														*			
Washington, D. C	21	4:55 p. m.	6:45 p. m.	0.57	5:09 p. m.	5:26 p. m.	.01	.24	.38	.46	.50										
Wichita, Kans	14-15			0.59														.35			
Williston, N. Dak	19-20			1.09														*			
Wilmington, N. C	5-6			0.40														.33			
Winnemucca, Nev	11			0.15														.07			
Wytheville, Va	5			0.52														.27			
Yankton, S. Dak	18			0.35														.31			
Yellowstone Park, Wyo	1-2			0.34														*			

* Self-register not working. † Record partly estimated. ‡ No precipitation occurred during month.

TABLE III.—*Data furnished by the Canadian Meteorological Service, April, 1916.*

Stations.	Altitude above M. S. L.* Jan. 1, 1916.	Pressure.			Temperature of the air.						Precipitation.		
		Station reduced to mean of 24 hours.	Sea-level reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Mean maximum.	Mean minimum.	Highest.	Lowest.	Total.	Departure from normal.	Total snowfall.
	Feet.	*Inches.*	*Inches.*	*Inches.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	*Inches.*	*Inches.*	*Inches.*
St. John's, N. F	125	29.70	29.84	−0.05	37.0	+2.5	42.6	31.5	59	21	2.48	−1.68	8.2
Sydney, C. B. I	48	29.86	*29.90*	+ *.01*	36.2	+1.2	42.9	29.5	54	17	4.04	+0.19	6.0
Halifax, N. S	88	29.78	*29.89*	− *.07*	40.1	+2.8	47.5	32.7	62	24	5.62	+1.44	1.3
Yarmouth, N. S	65	29.79	29.86	− .10	39.2	+0.3	45.3	33.0	59	24	2.90	−0.69	1.7
Charlottetown, P. E. I	38	29.87	29.91	+ .01	36.9	+1.7	43.0	30.8	53	21	3.39	+0.74	11.5
Chatham, N. B	28	29.93	*29.95*	+ *.05*	39.2	+3.7	48.4	30.1	58	20	2.47	−0.16	7.9
Father Point, Que	20	29.92	29.94	+ .01	36.7	+3.5	42.6	30.9	52	12	0.12	−1.46	0.8
Quebec, Que	296	29.62	29.95	− .04	40.0	+4.9	48.1	32.0	63	18	1.26	−0.83	2.7
Montreal, Que	187	29.71	29.92	− .08	44.2	+4.5	52.1	36.3	66	22	1.58	−0.66	6.7
Stonecliffe, Ont	489	29.32	*29.94*	− *.08*	41.7	+3.8	52.8	30.6	72	14	1.41	−0.15	0.9
Ottawa, Ont	236	29.66	*29.99*	− *.03*	43.5	+3.5	51.9	35.1	71	20	3.34	+1.84	18.7
Kingston, Ont	285	29.62	29.94	− .08	43.9	+3.9	51.5	36.3	64	26	3.51	+1.72	1.4
Toronto, Ont	379	29.52	*29.94*	− *.08*	44.4	+3.6	51.9	36.9	69	25	3.24	+0.87	1.9
White River, Ont	1,244	29.59	*29.93*	− *.11*	33.4	+0.4	44.8	22.0	62	−10	2.33	+1.08	6.0
Port Stanley, Ont	592	29.31	29.97	− .05	41.6	+0.6	49.4	33.9	67	22	3.20	+0.73	1.1
Southampton, Ont	656	29.24	....	....	41.2	+2.5	48.8	33.7	69	21	3.12	+1.32	0.2
Parry Sound, Ont	688	29.23	29.93	− .09	41.4	+3.8	50.8	32.1	67	13	4.38	+2.67	12.0
Port Arthur, Ont	644	29.24	29.95	− .08	37.5	+4.0	46.0	29.0	64	14	3.15	+1.43	8.8
Winnipeg, Man	760	29.19	30.05	+ .03	37.3	+1.4	47.3	27.3	66	3	0.30	−0.75	0.2
Minnedosa, Man	1,690	28.17	30.02	+ .01	35.9	−0.1	46.8	25.1	65	3	0.81	−0.25	4.6
Qu'Appelle, Sask	2,115	27.70	29.99	.00	35.9	−1.5	45.4	26.4	68	0	1.25	+0.20	7.6
Medicine Hat, Alberta	2,144	27.64	*29.93*	+ *.01*	46.2	+1.7	61.3	31.2	85	16	0.18	−0.56	....
Swift Current, Sask	2,392	27.35	*29.93*	− *.03*	41.4	+0.1	53.9	28.9	80	18	0.62	−0.31	3.8
Calgary, Alberta	3,428	26.39	*29.94*	+ *.04*	43.0	+3.4	37.0	29.1	76	22	0.85	−0.21	3.2
Banff, Alberta	4,521	25.35	*29.96*	+ *.06*	38.0	+4.7	48.7	27.4	69	19	2.48	+1.40	21.7
Edmonton, Alberta	2,150	27.63	*29.93*	+ *.04*	42.1	+2.2	54.2	30.1	70	17	1.17	+0.29	2.0
Prince Albert, Sask	1,450	28.40	*29.98*	*.00*	38.2	+2.1	49.9	26.6	75	2	1.21	+0.44	2.3
Battleford, Sask	1,592	28.19	*29.95*	− *.02*	40.2	+3.0	52.3	28.0	76	15	0.73	+0.26	....
Kamloops, B. C	1,262	28.76	30.07	+ .14	49.7	+0.8	61.4	38.1	74	28	0.57	+0.18	....
Victoria, B. C	230	29.84	30.10	+ .09	48.0	+1.2	54.4	41.5	63	37	1.12	−1.25	....
Barkerville, B. C	4,180	25.66	30.00	+ .14	35.2	+2.1	44.5	26.0	59	12	3.50	+1.68	28.0
Hamilton, Bermuda	151	29.83	30.00	− .05	64.0	+0.1	69.4	58.6	73	51	3.24	−0.94	....

*The altitudes given above were furnished by the Director of the Canadian Meteorological Service, Mar. 9, 1916, and refer to cisterns of barometers at the respective stations. Where sea-level pressures and departures are *italicized* new reduction factors are in course of computation.—C. A., jr.

Chart I. Hydrographs of Several Principal Rivers, April, 1916.

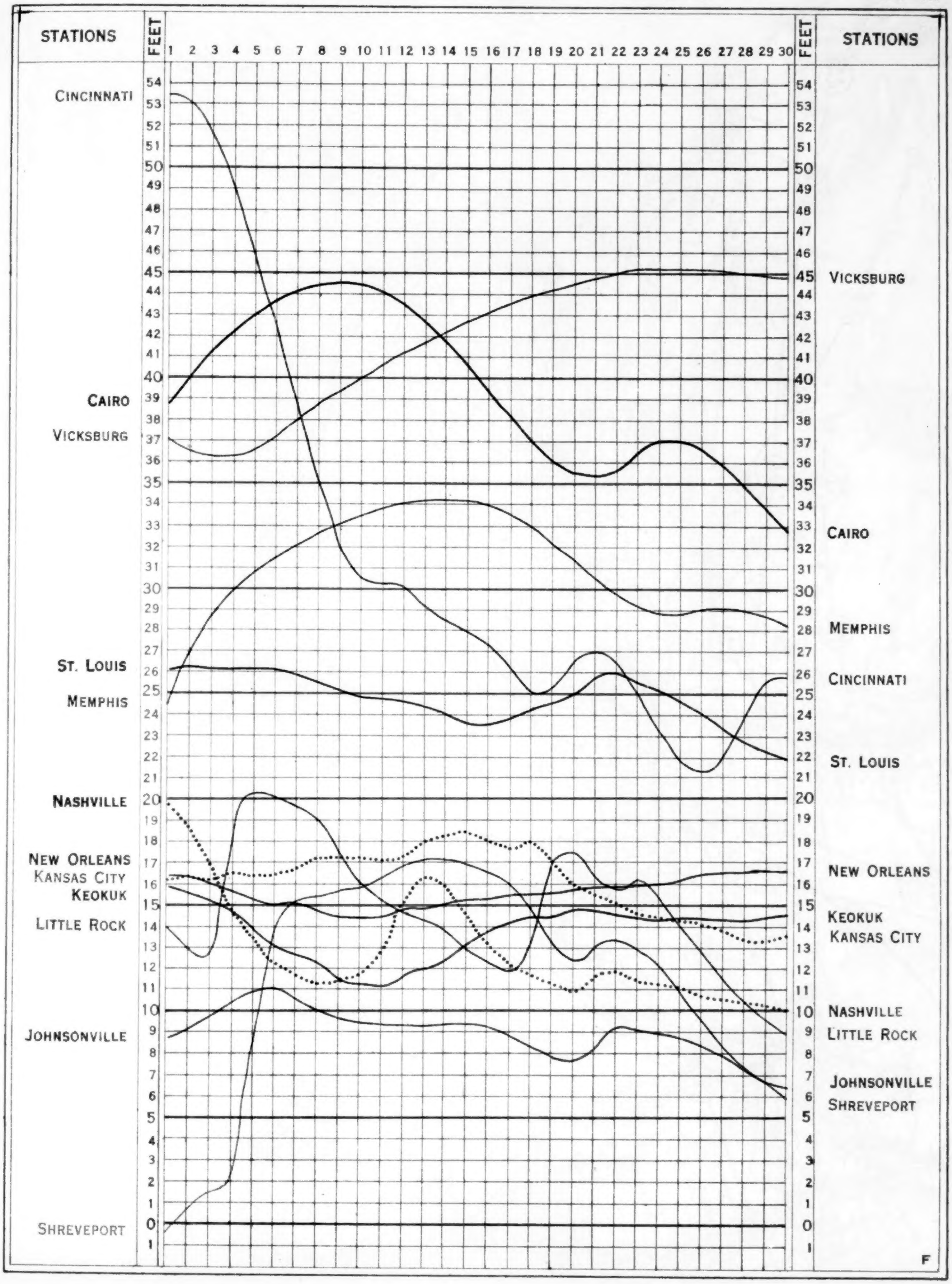

Chart II. Tracks of Centers of High Areas, April, 1916.
(Plotted by R. H. Weightman.)

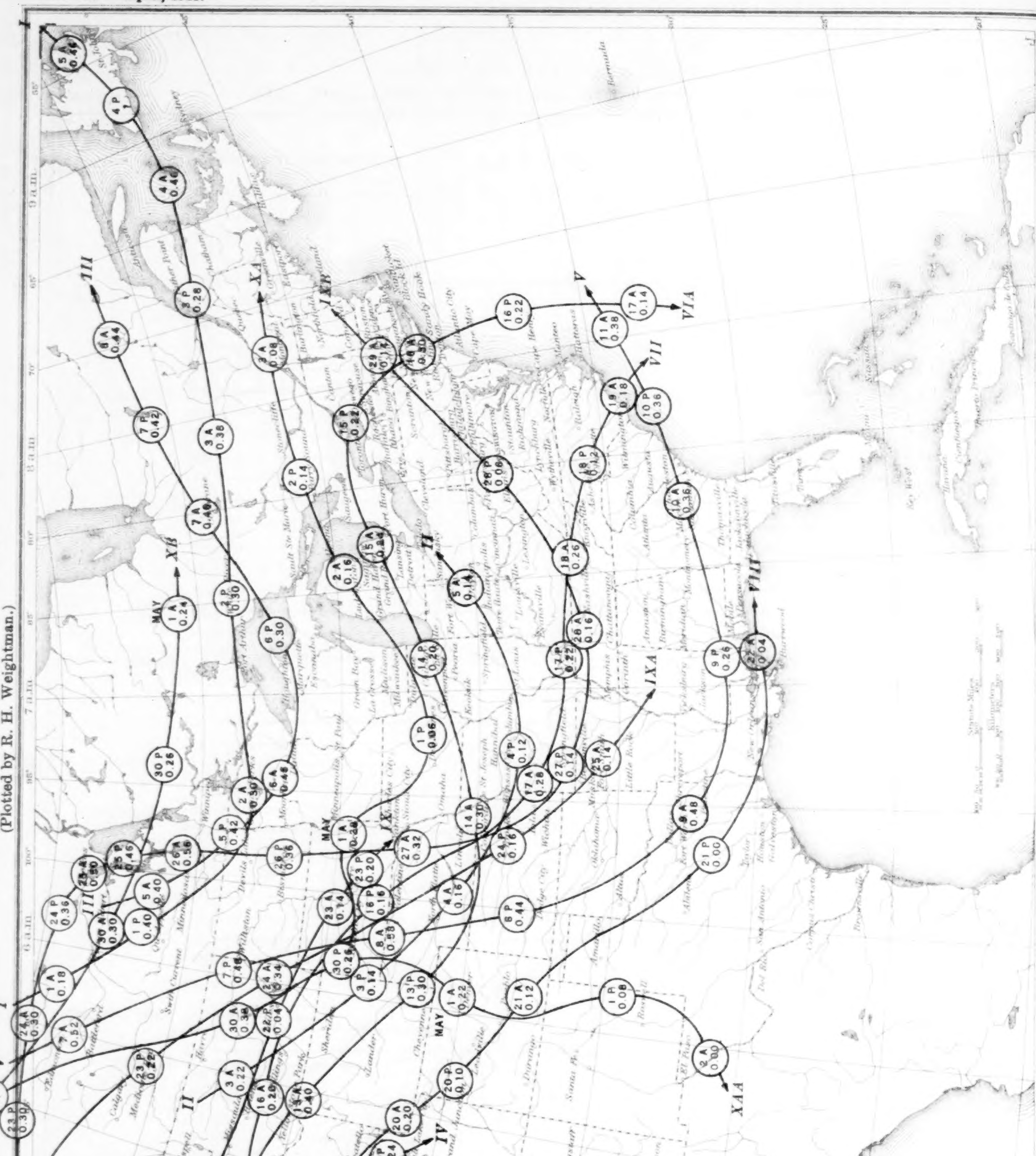

Chart III. Tracks of Centers of Low Areas, April, 1916.
(Plotted by R. H. Weightman.)

Chart III. Tracks of Centers of Low Areas, April, 1916.
(Plotted by R. H. Weightman.)

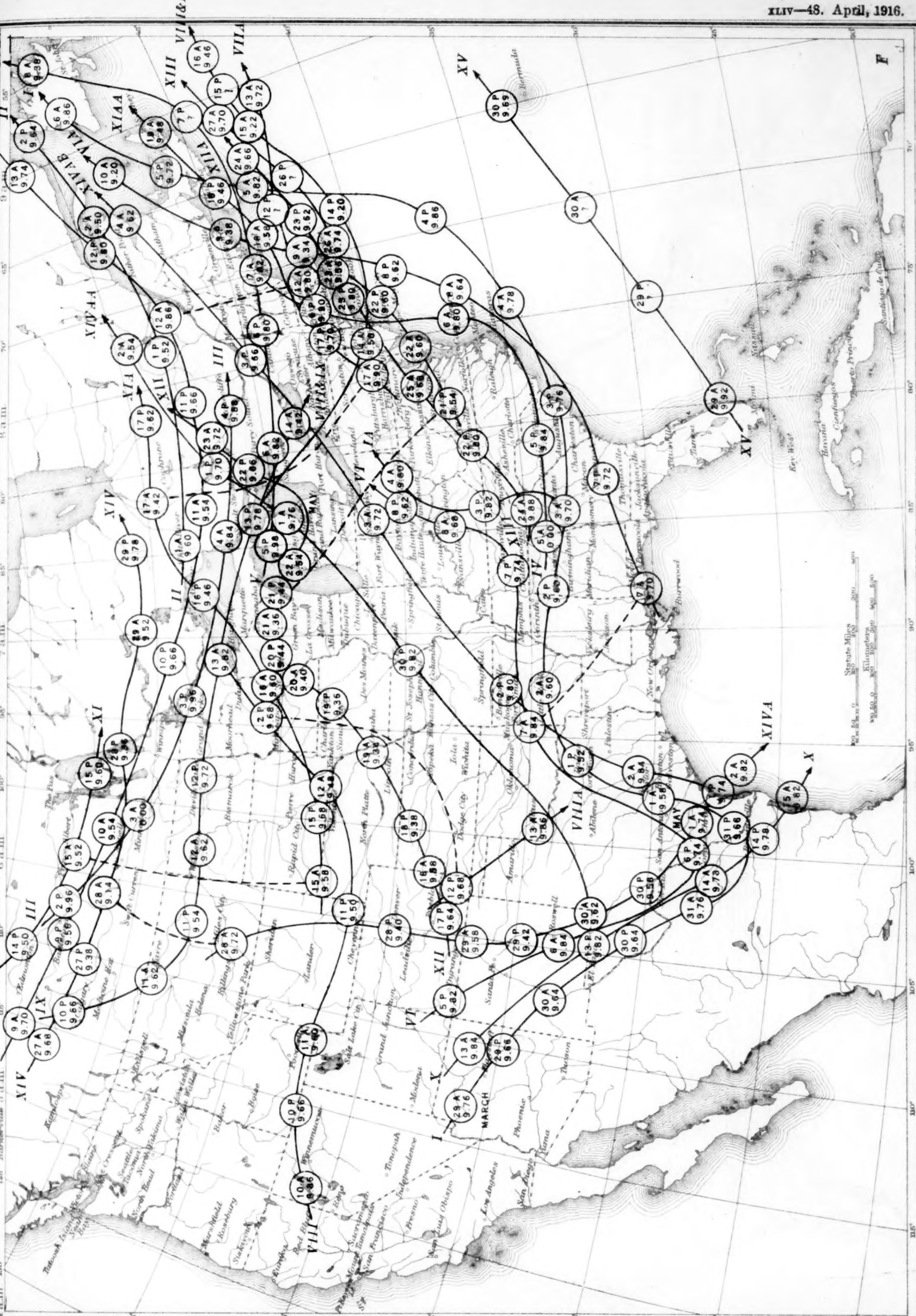

Chart IV.[5] Departure (°F.) of the Mean Temperature from the Normal, April, 1916.

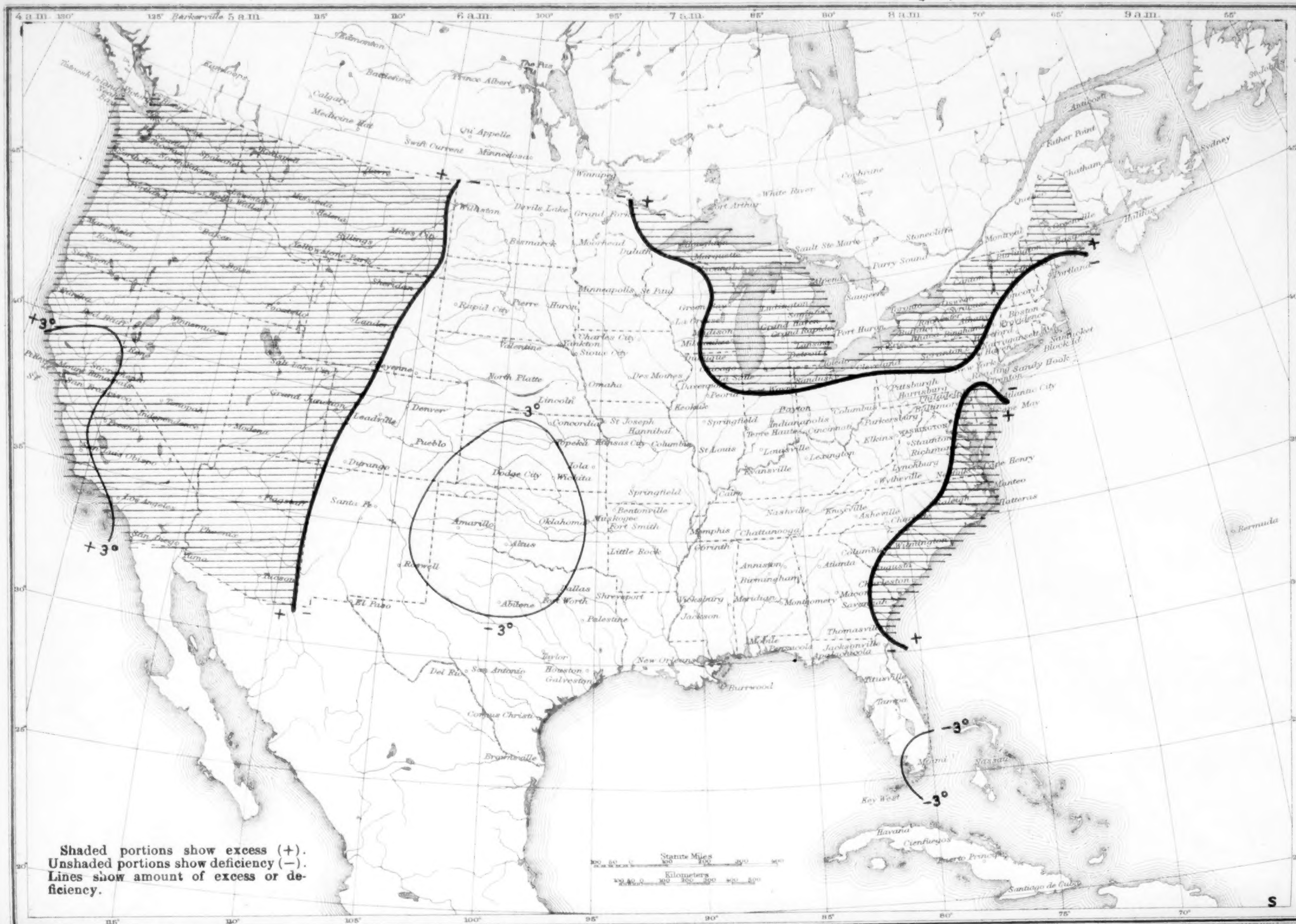

Chart V. Total Precipitation, April, 1916.

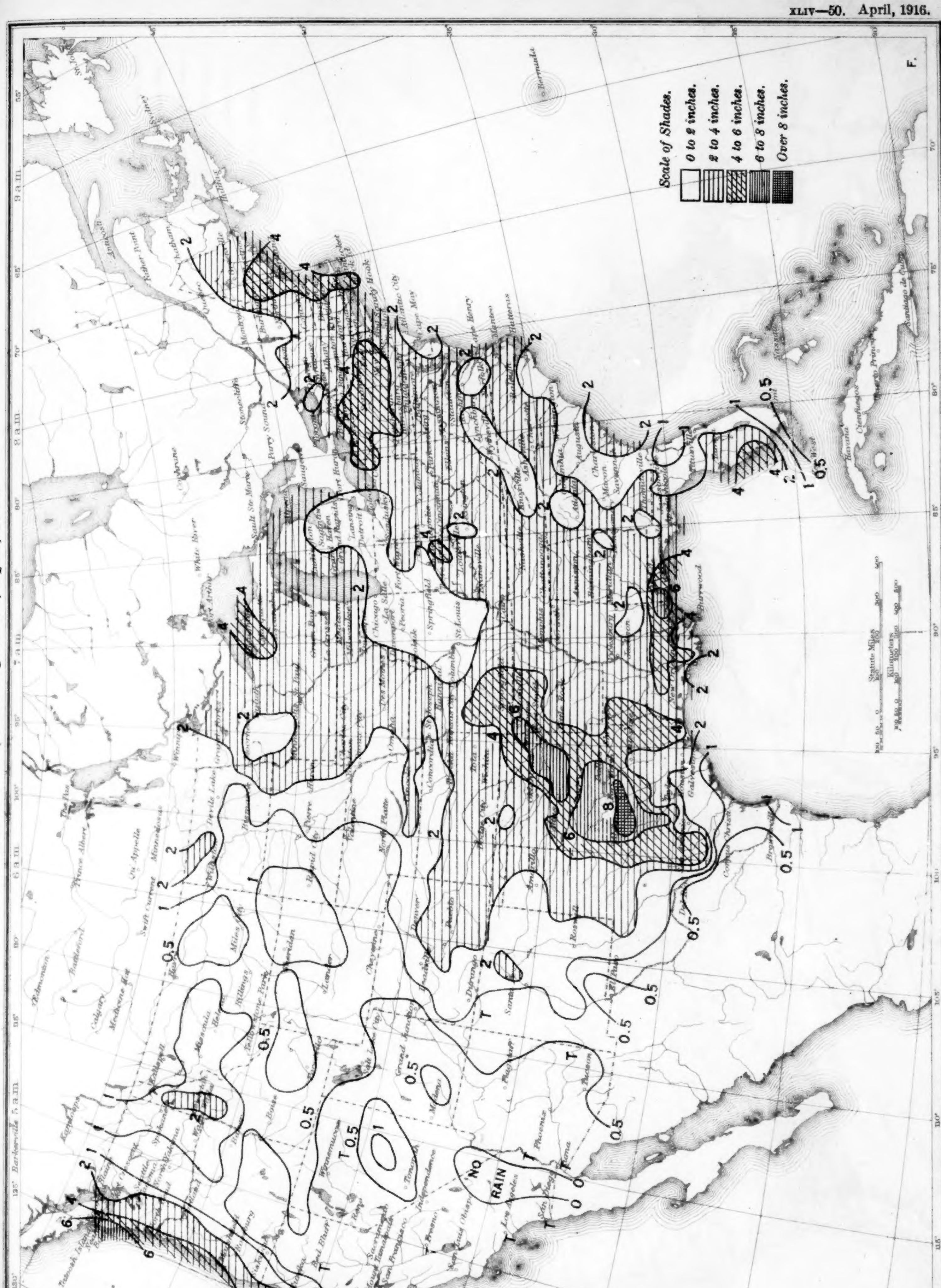

Chart VI. Percentage of Clear Sky between Sunrise and Sunset, April, 1916.

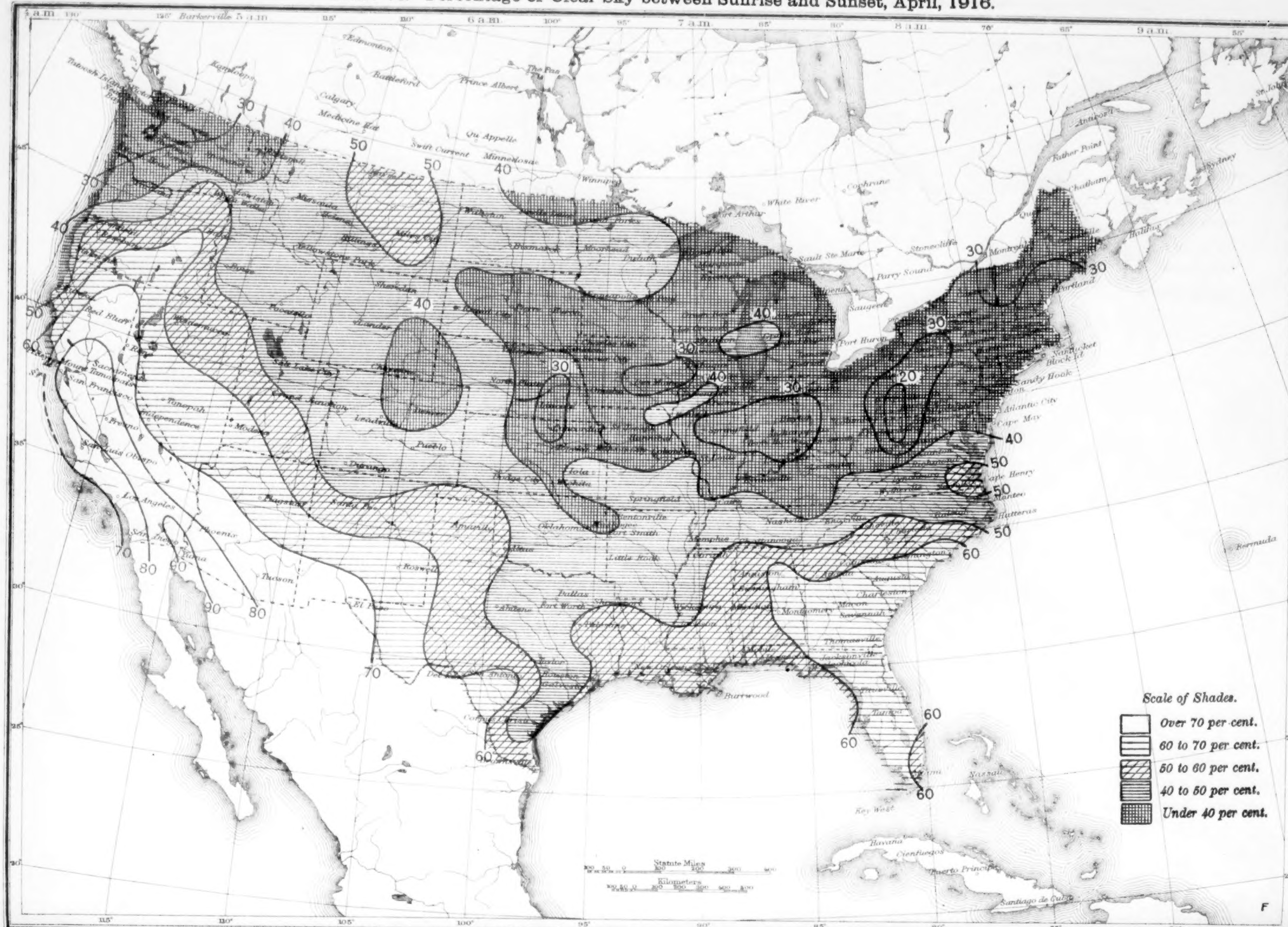

Chart VII. Isobars and Isotherms at Sea Level; Prevailing Winds, April, 1916.

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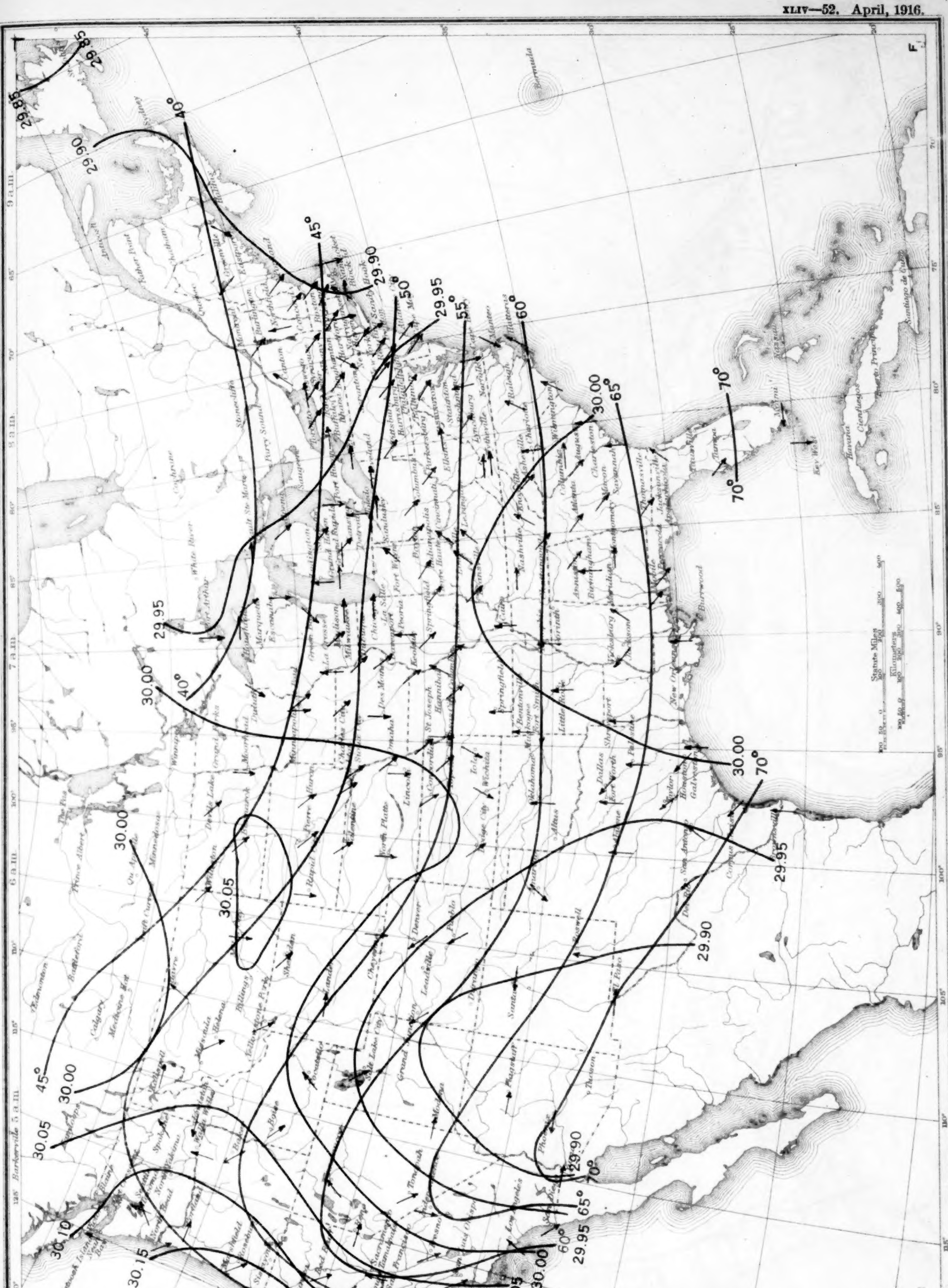

Chart VIII. Total Snowfall, Inches, April, 1916.

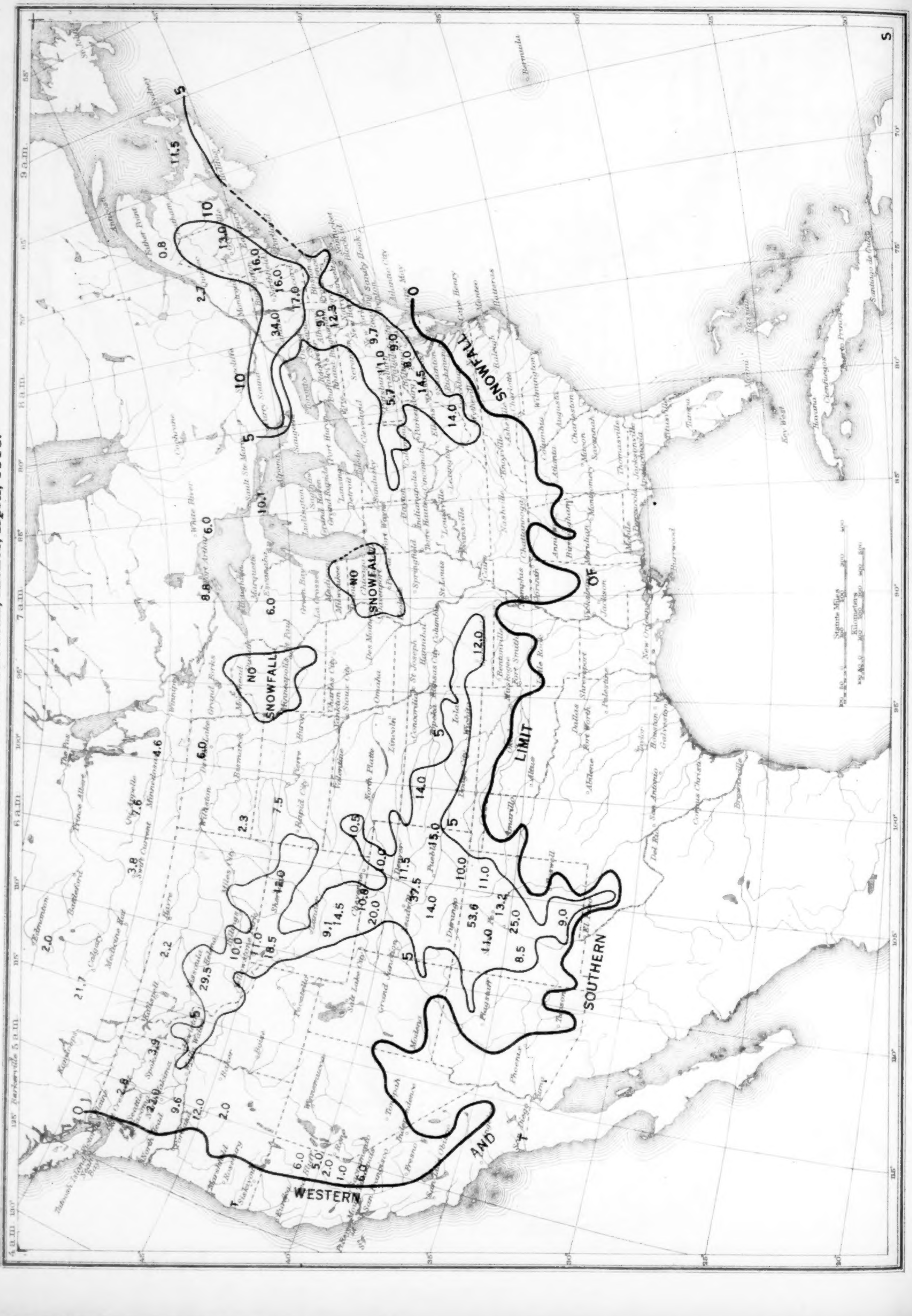

Chart IX. Means of Meteorological Data for North Atlantic Ocean, April, 1915.
(Plotted by F. A. Young.)

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(Plotted by F. A. Young.)